THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant —*Novum Organum, Præfatio.*

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FOR 1922.

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SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

MCMXXII.

List

OF THE

OFFICERS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

Elected February 17th, 1922.

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Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
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Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
John Frederick Norman Green, B.A.
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Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.
Walter Campbell Smith, M.C., M.A.
Sir Aubrey Strahan, K.B.E., Sc.D., LL.D., F.R.S.
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M. St. John Hope.

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Mr. R. S. Herries, *Treasurer*.

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Prof. W. S. Boulton.
Dr. J. S. Flett.
Prof. E. J. Garwood.
Mr. J. F. N. Green.
Dr. F. H. Hatch.
Prof. O. T. Jones.
Mr. R. D. Oldham.
Dr. G. T. Prior.
Prof. S. H. Reynolds.
Sir Aubrey Strahan.
Dr. H. H. Thomas.
Prof. W. W. Watts.
Mr. H. Woods.

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PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1921–22.

November 9th, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the arrears of their Annual Contributions.

The President made the following announcement:—'I have to report to the Society the loss of two old and valued Fellows. The Earl of Ducie was elected in 1853, and, although not the most senior on our list, was the oldest Fellow with whom we had maintained communication; throughout the long period of his Fellowship he has continuously shown interest in geology and helpfulness towards geologists. In Dr. Henry Woodward we lose a valued and familiar friend, and a very regular attendant at our meetings until quite recent years, when age and failing health prevented his presence. Elected in 1864, he had served for many years on the Council and in other offices of the Society, including the Presidency; but his greatest service to geology was probably the founding of the 'Geological Magazine,' which he conducted continuously from its initiation until a couple of years ago. The Council has already recorded its sympathy with his family in their bereavement, and I feel sure that you will wish to associate yourself with its action.'

The announcement was received by the Fellows present standing.

The following communications were read:—

1. 'The Igneous and Associated Rocks of Llanwrtyd (Brecon).' By Laurence Dudley Stamp, D.Sc., A.K.C., F.G.S., and Sidney William Wooldridge.

2. 'The Base of the Devonian, with especial reference to the Welsh Borderland.' By Laurence Dudley Stamp, D.Sc., A.K.C., F.G.S.

Downtonian fossils from Corvedale (Shropshire) were exhibited by W. Wickham King, F.G.S.

November 23rd, 1921.

Mr. R. D. Oldham, F.R.S., President, in the Chair.

Andrew Menzies, Assoc.R.S.M., c/o The British Union Oil Company, Bridgetown (Barbados), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Lower Carboniferous Rocks of West Cumberland.' By Kenneth Wilson Earle, M.Sc., F.G.S.

2. 'A Composite Sill at Newton Abbot (Devon).' By William George St. John Shannon, B.Sc., F.G.S.

Prof. E. J. Garwood exhibited the earliest recorded freshwater Gasteropod (*Viviparus* [*Paludina*]) from the local base of the Carboniferous rocks, near Horton-in-Ribblesdale (Yorkshire).

December 7th, 1921.

Mr. R. D. Oldham, F.R.S., President, in the Chair.

Geoffrey William Allen, B.A., B.Sc., c/o H. Mewton, The Cliffe, Tutbury (Staffordshire); Violet Ruby Barge, B.A., 29 Guilford Street, W.C. 1; Isaac Bond, B.Sc., Fairfield, Marlborough (Wiltshire); Herbert Rosslyn Budgell, Headmaster of Carshalton College, Carshalton (Surrey); John Albert Child, B.Sc., 60 Holland Park, W. 11; Ritchie Brinley Davies, Bryn-

mawr House, Gilfach Goch, Bridgend (Glamorgan); Arthur Broughton Edge, Tudor House, Maidenhead; Daniel Griffiths, Granville House, Pontypool (Monmouthshire); the Rev. Harold Edward Grindley, M.A., Bosbury Vicarage, Ledbury (Herefordshire); Wesley Hancock, B.Sc., Ashdene, Lower Ladywood, near Walsall (Staffordshire); Harold Hopkins, M.C., B.Sc., 16 Whitby Road, Fallowfield, Manchester; Robert Springett Mackilligin, Hurstbourne Tarrant, Andover (Hampshire); Jacob Thomas Morgan, Glasfryn, Nelson, Cardiff; Frank Mortimer Penney, 176 Lower Addiscombe Road, Croydon; Frederick Anselm Redmond, B.Sc., Assistant Professor of Civil Engineering in the University of Hongkong; Claude George Sara, Tabaquite (Trinidad); and the Rev. John Charles Thompson, 6 Bedford Avenue, Bexhill-on-Sea (Sussex), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Jurassic Chronology: II.—Preliminary Studies. Certain Jurassic Strata near Eype's Mouth (Dorset): the Junction-Bed of Watton Cliff and Associated Rocks.' By S. S. Buckman, F.G.S.

2. 'Banded Precipitates of Vivianite in a Saskatchewan Fireclay.' By John Stansfield, B.A., F.G.S.[1]

A small specimen of plattnerite (lead dioxide), a very rare mineral recently rediscovered at Leadhills (Lanarkshire), was exhibited by W. Campbell Smith, M.C., M.A., Sec.G.S.

December 21st, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Nature and Origin of the Pliocene Deposits of the County of Cornwall, and their bearing on the Pliocene Geography of the South-West of England.' By Henry Brewer Milner, M.A., D.I.C., F.G.S.

2. 'The Phosphate Deposit of Ocean Island.' By Launcelot Owen, A.R.S.M., A.R.C.S., F.G.S.

[1] Withdrawn by permission of the Council.

Microscope-slides and lantern-slides were exhibited by Mr. H. B. Milner, in illustration of his paper; and rock-specimens and lantern-slides by Mr. L. Owen, in illustration of his paper.

January 4th, 1922.

Dr. G. T. Prior, F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—Richard Mountford Deeley, M.Inst.C.E., and John Frederick Norman Green, B.A.

The appointment of Mr. N. E. Pettitt as Junior Assistant was announced and confirmed.

The following communication was read:—

'Shales-with-Beef, a Sequence in the Lower Lias of the Dorset Coast.' By William Dickson Lang, Sc.D., F.G.S., Leonard Frank Spath, D.Sc., F.G.S., and William Alfred Richardson, M.Sc., F.G.S.

Specimens and lantern-slides were exhibited by Dr. W. D. Lang, Dr. L. F. Spath, and Mr. W. A. Richardson, in illustration of their paper.

January 18th, 1922.

Mr. R. D. Oldham, F.R.S., President, in the Chair.

Herbert Edward Bradshaw, A.R.S.M., 40 Eardley Crescent, Earl's Court, S.W. 5; Major Edwin Massey Bull, 276 Holmesdale Road, South Norwood, S.E. 25; Harry Brenan Cronshaw, B.A., Ph.D., A.R.S.M., The Briars, Penn, Wolverhampton; Frederick Henry Dodd, 51 Shooters' Hill Road, Blackheath, S.E. 3; Harold Marriot Gell, A.M.Inst.C.E., 187 Northfield Avenue, West Ealing, W. 13; Sydney George Clift, B.Sc., 137 Willingham Street, Grimsby; Frank Gossling, B.Sc., F.C.S., 15 Birdhurst Road, Croydon; Timothy Hallissy, Senior Geologist, Geological Survey of Ireland, 39 Eaton Square, Terenure (County Dublin); Sydney

Ewart Hollingworth, B.A., Geologist, H.M. Geological Survey, Flore, near Weedon (Northamptonshire); Arthur Lovatt, B.Sc., 31 Park Road, Hendon, N.W. 4; James Mitchell, B.Sc., B.E., Professor of Geology & Mineralogy in University College, Galway; John Isaac Platt, B.Sc., Assistant Lecturer in Geology, University College, Aberystwyth; George Robling, Llwyncelyn, Ponthenry, Llanelly; Harry Hall Sands, Milton Chambers, Nottingham; and Walter Percy Winter, B.Sc., 20 Hurst Wood Road, Shipley (Yorkshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Jurassic Plants from Ceylon.' By Prof. Albert Charles Seward, Sc.D., F.R.S., F.G.S., and R. E. Holttum, B.A.

2. 'The Carboniferous Limestone (Avonian) of Broadfield Down (Somerset).' By Frederick Stretton Wallis, M.Sc., F.G.S.

February 1st, 1922.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

Arthur Bond, B.A., 31 Croxted Road, Dulwich, S.E. 21; James Percy Tufnell Burchell, Fawke House, Sevenoaks (Kent); Francis Henry Arnold Engleheart, B.A., The Priory, Stoke-by-Nayland, near Colchester; Kenneth Stuart Sandford, B.A., University College, Oxford; and James Alfred Steers, B.A., 2 Goldington Avenue, Bedford, were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. Cyril Edward Nowill Bromehead, B.A., F.G.S., delivered a lecture on the Influence of Geology on the History of London.

The 6-inch Geological Survey maps constructed by the Lecturer were exhibited, and some of the new features pointed out. The small streams now 'buried' are indicated on the maps, and the historical research involved in tracing them led to an appreciation of the connexion between the geology and topography on the one hand, and the original settlement and gradual growth of London on the other. The reasons for the first selection of the site have been dealt with by several writers: below London the wide alluvial marshes formed an impassable obstacle; traffic from the Continent came by the ports of Kent, and, if destined for the

north or east of Britain, sought the lowest possible crossing of the Thames. This was near old London Bridge, where the low-level gravel on the south and the Middle Terrace deposits on the north approached close to the river-bank. A settlement was obviously required here, and the northern side was chosen as the higher ground. The gravels provided a dry healthy soil and an easily accessible water-supply; they crowned twin hills separated by the deep valley of the Walbrook, bounded on the east by the low ground near the Tower and the Lea with its marshes, and on the west by the steep descent to the Fleet; the site was, therefore, easily defensible. The river-face of the hills was naturally more abrupt than it is now, owing to the reclamation of ground from the river; the most ancient embankment lay 60 feet north of the northern side of Thames Street.

The first definite evidence of a permanent settlement was the reference in Tacitus. The early Roman encampment lay east of the Walbrook, and the brickearth on the west around St. Paul's was worked. Later the city expanded, until the St. Paul's hill was included, the wall being built in the second half of the 4th century. The great Roman road from Kent (Watling Street) avoided London, and utilized the next ford upstream—at Westminster—on its way to Verulamium and the north-west. The earliest Westminster was a Roman settlement beside the ford, built on a small island of gravel and sand between two mouths of the Tyburn. This settlement could not grow, as did London, since the area of the island, known to the Saxons as Thorney, was small. The road from London to the west joined the St. Alban's road at Hyde Park Corner, running along the 'Strand,' where the gravel came close to the river; a spring thrown out from this gravel by the London Clay was utilized for the Roman Bath in Strand Lane.

Throughout Mediæval times London was practically confined to the walled city, a defensible position being essential. The forests of the London-Clay belt on the north are indicated in Domesday Book and referred to by several writers, notably Fitzstephen, whose Chronicle also mentions many of the springs and wells and the marsh of Moorfields, produced largely by the damming of the Walbrook by the Wall. The same writer mentions that London and Westminster are 'connected by a suburb.' This was along the 'Strand,' and consisted first of great noblemen's houses facing the river and a row of cottages along the north side of the road; this link grew northwards, at first slowly, but in the second half of the 17th century with great rapidity. By the end of that period the whole of the area covered by the Middle-Terrace Gravel was built over, but the northern margin of the gravel was also that of the town for 100 years, the London-Clay belt remaining unoccupied.

The reason for this arrested development was that the gravel provided the water-supply. In early days the City was dependent on many wells sunk through the gravel, some of which were famous,

such as Clerkenwell, Holywell, and St. Clement's. In the same way the outlying hamlets (for instance, Putney, Roehampton, Clapham, Brixton, Ealing, Acton, Paddington, Kensington, Islington, etc.) started on the gravel, but later outgrew it, as pointed out by Prestwich in his Presidential Address of 1873. In the City the supply soon became inadequate, or as Stow says 'decayed,' and sundry means were adopted to supplement it. The conduit system, bringing water in pipes from distant springs, began in 1236; London-Bridge Waterworks pumped water from the Thames by water-wheels from 1582 to 1817; the New River was constructed in 1613, and is still in use. It was not until the 19th century that steam-pumps and iron pipes made it possible for the clay area to be occupied, thus linking together the various hamlets that are now the Metropolitan Boroughs.

Some of the ways in which Geology affects London to-day were briefly indicated, and the lecture was illustrated by a number of lantern-slides, reproduced mainly from old maps and prints.

The cordial thanks of the Meeting were accorded to the Lecturer.

ANNUAL GENERAL MEETING.

February 17th, 1922.

RICHARD DIXON OLDHAM, F.R.S., President,
in the Chair.

REPORT OF THE COUNCIL FOR 1921.

DURING the year under review 56 new Fellows were elected into the Society (24 less than in 1920). Of the Fellows elected in 1921, 45 paid their Admission Fees before that end of that year, and, of the Fellows who had been elected in the previous year, 26 paid their Admission Fees in 1921, making the total accession of new Fellows during the past year amount to 71 (7 more than in 1920).

Allowing for the loss of 58 Fellows (17 resigned, 35 deceased, and 6 removed), but adding 1 Fellow re-instated, it will be seen that there is an increase of 14 in the number of Fellows (as compared with an increase of 21 in 1920).

The total number of Fellows is, therefore, at present 1243, made up as follows: Compounders 198 (9 less than in 1920); Contributing Fellows 1036 (24 more than in 1920); and Non-Contributing Fellows 9 (1 less than in 1920).

Turning now to the Lists of Foreign Members and Foreign Correspondents, the Council announces with regret the decease during the past year of Prof. A. G. Nathorst, Foreign Member. There are now three vacancies in the list of Foreign Members, and twelve vacancies in the list of Foreign Correspondents.

The total Receipts from all ordinary sources of income amounted to £3894 5*s.* 8*d.*, and the ordinary Expenditure of the year to £3964 12*s.* 9*d.* In addition, there was Special Expenditure on arrears of publication amounting to £897 17*s.* 6*d.*, and there were Special Receipts amounting to £732 18*s.* 6*d.* from the sale of investments and transfer from the Sorby and Hudleston Bequests and from the Prestwich and Barlow-Jameson Funds.

In the estimates for the current year it has been possible to establish a balance between ordinary income and expenditure, and to provide an increased allotment for the Quarterly Journal. Of special expenditure there are still outstanding certain commitments, amounting to about £450, which may have to be met during the year by realization of part of the invested funds of the Society, or in some other manner, as may be decided by the Fellows at a Special General Meeting.

All publications belonging to 1921 were issued and brought to account during the year. Six parts of the Quarterly Journal were

published, constituting the remainder of Vol. LXXVI and the whole of the current volume for the year, Vol. LXXVII. The List of Geological Literature for 1913 (the compilation of which had been commenced by Mr. C. P. Chatwin during his tenure of the Librarianship, and completed after his retirement from that office) and that for 1920 (Authors & Titles) were also published within the year, and great progress has been made in the compilation of the List for the years 1915–1919.

During the year the Council has given consideration to the Card Catalogue and List of Geological Literature. In view of the present financial position and commitments of the Society, it decided that the publication of the subject-index must be discontinued for the present. The Council expresses its regret that this action, which it recognizes as seriously diminishing the value of the publication, should be necessary, and regards the resumption of the subject-index as a matter which must be kept in mind, when improvement in the financial conditions of the Society permits. In the altered conditions it became unnecessary to continue the arrangement with Mr. C. D. Sherborn, by which he edited the Card Catalogue and incorporated the cards for both authors and subjects from year to year since he commenced the Catalogue in 1901. In terminating this arrangement the Council recorded its appreciation of Mr. Sherborn's past services in the preparation of the Card Catalogue.

The Apartments of this Society have been used for General and for Council Meetings during the past year by the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Prehistoric Society of East Anglia, the Ray Society, the Conjoint Board of Scientific Societies, and the South-Eastern Union of Scientific Societies.

Sir Aubrey Strahan and Prof. W. G. Fearnsides continued to act during the year 1921 as the Geological Society's representatives on the Conjoint Board of Scientific Societies, and Mr. R. D. Oldham was nominated to represent this Society on the Geophysical Committee of the Royal Astronomical Society.

The Proceeds of the Daniel-Pidgeon Fund for 1921 were awarded to Mr. Frederic Stretton Wallis, of Bristol University and the Bristol Museum, who proposes to carry out researches on the Old Red Sandstone and the Carboniferous Limestone of the Bristol District; and to Mr. Ralph Walter Segnit, of Oxford University, who proposes to carry out an investigation of the stratigraphical distribution of the Cornbrash, based on a study of its faunal succession.

Further, the following Awards of Medals and Funds have been made:—

The Wollaston Medal to Dr. Alfred Harker, in recognition of his researches concerning the Mineral Structure of the Earth, especially in connexion with the natural history of igneous rocks.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, to Dr. John William Evans, as an acknowledgment of the value of his researches, and in recognition of the manifold services that he has rendered to geological science.

The Lyell Medal, together with a sum of Twenty-five Pounds from the Lyell Geological Fund, to Dr. Charles Davison, in recognition of the value of his seismological researches and their bearing on the science of geology.

The Balance of the Proceeds of the Wollaston Donation Fund to Dr. Leonard Johnston Wills, as a mark of appreciation of his work on the older stratified rocks of the Midlands and the Welsh Borderland, and to encourage him in further endeavour.

The Balance of the Proceeds of the Murchison Geological Fund to Mr. Herbert Bolton, in recognition of the value of his detailed researches in geology, particularly with regard to the insect-remains and faunal horizons of the Coal Measures of this country.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Arthur Macconochie, in recognition of devoted service to the science of geology and the value of his work among the fossiliferous rocks of Scotland, more particularly the Cambrian of the North-West Highlands, and the Ordovician and Silurian of the Southern Uplands.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. David Tait, as a mark of appreciation of his valued contributions to Scottish geology, on stratigraphy, palæontology, and petrology, and especially in connexion with the Carboniferous rocks of the Lothians.

Report of the Library Committee for 1921.

The Donations received during the year 1921 number 56 Volumes of separately-published Works, 389 Pamphlets, and 4 detached Parts of Works, also 228 Volumes and 376 detached Parts of Serial Publications, 133 Volumes and 243 Parts of the Publications of Geological Surveys and other Public Bodies, and 10 Volumes of Weekly Periodicals.

As many as 59 sheets of Geological Maps were received during the year.

The number of accessions by Donation amounts, therefore, to 427 Volumes, 389 Pamphlets, and 623 detached Parts.

The Donors during the preceding year included 110 Government Departments and other Public Bodies, 130 Societies and Editors, and 112 Personal Donors.

Considerable progress has been made with the resumption of exchanges with Societies and Institutions of former enemy countries. Most of the publications of such bodies, issued between the years 1914 and 1919 inclusive, have now been received in the Library, and the exchange of their future publications has been arranged.

The Author and Subject Slips for the year 1918 have now been incorporated with the Card Catalogue, and the Author Slips for the year 1920 are in process of insertion.

The Purchases included 34 Volumes and 17 detached Parts of Works, and 6 Volumes and 18 detached Parts of Works published serially, and 4 Sheets of Geological Maps.

The Expenditure incurred in connexion with the Library during 1921 was as follows:—

	£	s.	d.
Books and Periodicals	62	19	9
Binding and Map-Mounting	94	7	5
Sundries	7	10	0
Total	£164	17	2

The appended Lists contain the Names of Government Departments and other Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Alsace-Lorraine.—Service de la Carte Géologique. Strasbourg.
Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Australia (South), etc. *See* South Australia, *etc.*
Austria.—Geologische Reichsanstalt. Vienna.
Barcelona.—Junta de Ciencias Naturals.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique. Brussels.
Bergens Museum. Bergen.
Berlin.—Preussische Akademie der Wissenschaften.
Bristol Museum & Art Gallery.
British Columbia.—Ministry of Mines. Victoria (B.C.).
British Guiana.—Lands & Mines Department. Georgetown.
Brooklyn (N.Y.).—Museum of the Institute of Arts & Sciences.
Buenos Aires.—Museo Nacional.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Cambridge (Mass.).—American Academy of Arts & Sciences.
——. Museum of Comparative Zoology in Harvard College.

Canada.—Geological & Natural History Survey. Ottawa.
——. Department of Mines.
Cape of Good Hope.—South African Museum. Cape Town.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Denmark.—Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Federated Malay States.—Government Geologist. Kuala Lumpur.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de l'Instruction Publique. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Gold Coast.—Geological Survey. Accra.
Great Britain.—Colonial Office. London.
——. Geological Survey. London.
——. Imperial Institute. London.
——. Imperial Mineral Resources Bureau. London.
Holland.—Departement van Kolonien. The Hague.
Hungary.—Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois.—Geological Survey. Urbana (Ill.).
India.—Geological Survey. Calcutta.
——. Trigonometrical Survey. Dehra Dun.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Kansas University. Lawrence.
Kentucky.—Geological Survey. Frankfort (Ky.).
La Plata, Museo de.
Lausanne.—University of.
Liége.—Collège des Bourgmestres & Échevins.
Lisbon.—Academia das Sciencias.
London.—Metropolitan Water Board.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
Mexico.—Instituto Geológico. Mexico City.
——. Secretaria de Industria, Comercio & Trabajo. Mexico City.
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Minnesota.—School of Mines. Minneapolis.
Munich.—Bayerische Akademie der Wissenschaften.
Mysore.—Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
New Jersey.—Department of Conservation. Trentham (N.J.).
New South Wales.—Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Board of Science & Art. Wellington.
——. Geological Survey. Wellington.
Nigeria.—Geological Survey.
Norway.—Geologiske Undersökelse. Christiania.
Ohio.—Geological Survey. Columbus.
Padua.—Reale Accademia delle Scienze.
Paris.—Académie des Sciences.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Poland.—Service Géologique. Warsaw.
Portici.—Reale Scuola di Agricoltura.
Portugal.—Serviço Geológico. Lisbon.
Prussia.—Geologische Landesanstalt. Berlin.
Quebec.—Department of Colonization, Mines, & Fisheries.
Queensland.—Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Academia Românǎ. Bucarest.
Scotland.—Geological Survey. Edinburgh.
Sierra Leone.—Geological Survey. Freetown.
South Africa.—Department of Mines. Pretoria.

South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Southern Rhodesia.—Geological Survey. Salisbury.
Spain.—Instituto Geologico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
——. Geological Survey. Hobart.
Tôhoku.—Imperial University of Sendai.
Tokio.—College of Science.
Turin.—Reale Accademia delle Scienze.
Uganda.—Geological Department. Entebbe.
United States.—Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Victoria (Australia), Agent-General for. London.
—— (——). Geological Survey. Melbourne.
Vienna.—Akademie der Wissenschaften.
——. Naturhistorisches Hofmuseum.
Wales.—National Museum. Cardiff.
Washington (D.C.).—Smithsonian Institution.
——. Geophysical Laboratory.
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia.—Department of Mines. Perth.
——. Geological Survey. Perth.

II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Basel.—Naturforschende Gesellschaft.
Belfast.—Natural History Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Institut für Meereskunde & Geographisches Institut.
——. Zeitschrift für Berg-, Hütten-, und Salinenwesen.
Berne.—Naturforschende Gesellschaft.
Bonn.—Naturhistorischer Verein der preussischen Rheinlande.
Bordeaux.—Société Linnéenne.
Boston (Mass.).—American Academy of Arts & Sciences.
——. Society of Natural History.
Bristol Naturalists' Society.
Brussels.—Société Belge de Géologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Bucarest.—Annales des Mines de Roumanie.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Cientifica Argentina.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat.—Naturforschende Gesellschaft.
Dublin.—'The Irish Naturalist.'
——. Royal Dublin Society.
Edinburgh.—Royal Scottish Geographical Society.
——. Royal Society.
Falmouth.—Royal Cornwall Polytechnic Society.

Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- und Heilkunde.
Gloucester.—Cotteswold Naturalists' Field-Club.
Hague.—Société Hollandaise des Sciences.
Halifax.—Yorkshire Geological Society.
Halle.—Leopoldinisch-Carolinische deutsche Akademie der Naturforscher.
——. Zeitschrift für praktische Geologie.
Helsingfors.—Société Finlandaise de Géographie.
Johannesburg.—Geological Society of South Africa.
Königsberg (Prussia).—Physikalisch-Œkonomische Gesellschaft.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Leipzig.—Zeitschrift für Krystallographie.
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences de Liége.
Lille.—Société Géologique du Nord.
Lima.—Sociedad de Geográfia.
Liverpool Geological Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Magazine.'
——. 'Nature.'
——. 'The Naturalist.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Ray Society.
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Engineers.
——. South-Eastern Union of Scientific Societies.
——. 'Water.'
——. Zoological Society.
Manchester.—Literary & Philosophical Society.
Melbourne (Victoria).—Australasian Institute of Mining & Metallurgy.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Milan.—Società Italiana di Scienze Naturali.
Modena.—Società Sismologica Italiana.
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'

New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
Northampton.—Northamptonshire Natural History Society.
Ottawa.—Royal Society of Canada.
Paris.—Annales des Mines.
——. Société Géologique de France.
Perth.—Perthshire Society of Natural Sciences.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Scientifique & Médicale de l'Ouest.
——. Société Géologique & Minéralogique de Bretagne.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—Verein für Naturkunde Württembergs.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Royal Canadian Institute.
Torquay Natural History Society.
Upsala.—Geological Institution of the University.
Vienna.—Geologische Gesellschaft.
——. Berg- und Hüttenmännisches Jahrbuch.
——. Zoologische-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Geological Society of America.
Wiesbaden.—Nassauischer Verein für Naturkunde.
Worcester.—Naturalists' Club.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Abelspies, J. F. C.
Adolf, G.
Aguilar y Santillan, R.
Assmann, P.

Barrell, J.
Bekker, H.
Bell, A.
Bell, N. A.
Bosworth, T. O.
Brière, Y.
Brown, J. Coggin.
Burckhardt, C.

Carus-Wilson, C.
Chapman, F.
Clarke, E. de C.
Clarke, F. W.
Cole, J. A. G.
Crema, C.

Dall, W. H.
Daly, R. A.
Davies, David.
Davison, E. H.
Delhaye, F.
Ditmas, F. I. L.
Dixon, E. E. L.
Dollfus, G. F.
Dorlodot, H. de.
Douvillé, H.
Drygalski, E. von.

Erdtmann, O. G. E.

Fleury, E.
Foshag, W. F.

Gardiner, C. I.
Green, J. F. N.

Halle, T. G.
Harmer, F. W.
Haughton, S. H.
Henderson, J.
Hobson, B.
Holmes, A.
Holmquist, P. J.
Howchin, W.
Hume, G. S.

Jahn, A.
Jones, T. A.

King, W. W.
Kunz, G. F.

Launay, L. de.
Leach, A. L.
Leslie, T. N.
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Lugeon, M.
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McConnell, P.
Marriott, R. A.
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Martin, E. A.
Marty, P.
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Mohr, H.
Moir, J. R.
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Morgan, P. G.

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Penzer, N. M.
Peragallo, M.
Pilgrim, L.
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Pruvost, P.

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Reed, F. R. C.
Reid, Mrs. E. M.
Renier, A.
Reynolds, S. H.
Richardson, W. A.
Roxo, M. G. de O.

Sargent, H. C.
Schlosser, M.
Schuchert, C.
Shannon, E. V.
Sheppard, T.
Smith, S.
Smith, W. Campbell.
Spath, L. F.
Spitaler, R.
Stamp, L. D.
Stevenson, S.
Stuart, M.
Sutton, J. R.

Taber, S.
Teilhard de Chardin, P.
Termier, P.
Thomson, G. M.
Thorpe, M. C.
Thorpe, M. R.
Tilley, C. E.
Torcelli, A. J.
Troxell, E. L.

Van Straelen, V.

Walther, J.
Washington, H. S.
Watts, W. W.
Wayland, E. J.
Wentworth, C. K.
Whitaker, W.
Whitehead, H.
Wieland, G. R.
Woodward, C. J.
Woolacott, D.

Comparative Statement of the Number of the Society at the Close of the Years 1920 and 1921.

	Dec. 31st, 1920.	Dec. 31st, 1921.
Compounders	207	198
Contributing Fellows	1012	1036
Non-Contributing Fellows	10	9
	1229	1243
Foreign Members	32	37
Foreign Correspondents	27	28
	1288	1308

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1920 and 1921.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1920		1229
Add Fellows elected during the former year and paid in 1921		26
Add Fellows elected and paid in 1921		45
Add Fellow reinstated		1
		1301
Deduct Compounders deceased	12	
Contributing Fellows deceased	22	
Contributing Fellows resigned	17	
Non-Contributing Fellow deceased	1	
Fellows removed in accordance with Sect. VI, Art. 5, of the Bye-Laws	6	
	—	58
		1243
Number of Foreign Members and Foreign Correspondents, December 31st, 1920	59	
Deduct Foreign Member deceased and Foreign Correspondent resigned	2	
Deduct Foreign Correspondents elected Foreign Members	6	
	51	
Add Foreign Members and Foreign Correspondents elected	14	
	65	
	—	65
		1308

Deceased Fellows.

Compounders (12).

Evans, M. [elected in 1872].
Feilden, Col. H. W. [el. 1875].
Fletcher, Sir Lazarus [el. 1879].
Hawkshaw, J. C. [el. 1866].
Love, J. [el. 1876].
Lucas, Col. F. [el. 1883].
Lucas, H. [el. 1864].
Mallett, F. R. [el. 1868].
Miall, L. C. [el. 1875].
Nicholas, W. [el. 1874].
Ridewood, W. G. [el. 1895].
Wrightson, Sir Thos. [el. 1876].

Contributing Fellows (22).

Clinch, G. [elected in 1899].
Davies, T. W. [el. 1896].
Douglas, T. [el. 1873].
Ducie, Earl of [el. 1853].
Fowler, G. [el. 1875].
Galloway, T. L. [el. 1876].
Garforth, Sir William [el. 1891].
Gwinnell, W. F. [el. 1889].
Harland, Rev. A. A. [el. 1878].
Hogben, G. [el. 1911].
Jenkins, D. M. [el. 1919].
Lavanchy, F. M. [el. 1906].
Longstaff, G. B. [el. 1906].
Maidwell, F. T. [el. 1919].
Molyneux, A. J. C. [el. 1897].
Pearse, A. L. [el. 1894].
Parke, G. H. [el. 1879].
Reeve, J. [el. 1901].
Wadsworth, M. E. [el. 1889].
Winwood, Rev. H. H. [el. 1864].
Woodward, H. [el. 1864].
Zabel, C. F. [el. 1919].

Non-Contributing Fellow (1).

Duckworth, H. [elected in 1858].

Fellows Resigned (17).

Allworthy, S. W.
Barnett, W. J.
Brown, E. G.
Brown, H. T.
Carpenter, S. W.
Clark, J. E.
Dodd, C.
Edwards, W.
Fenner, C.
Homan, B. van.
Hughes, W. E.
Mackenzie, G. L.
Peacock, A.
Pollen, Lt.-Col. C. H.
Robson, V. E.
Satow, P. A.
Taylor, T. G.

Fellows Removed (6).

Balcon, S.
Bowen, D.
Lubbock, M.
Rivington, W. R. G.
Schofield, E.
Wells, J.

Fellows Elected (71).

Bain, A. D. N.
Bisat, W. S.
Blanford, A. W.
Brown, J.
Budgell, H. R.
Burling, L. D.
Cave, C. J. P.
Charles, A. J.
Chilcott, B. G.
Clark, Rev. L. K.
Cornwall, I. E.
Cunnington, E. B. H.
Davies, D. J.
Davies, R. B.
Davies, S. J.
de Camps, E. B. E.
Dines, H. G.
Dixon, H. G. D.
Duncan, J. S.
Edge, A. B.
Erb, J. T.
Glenday, V.
Green, W.
Griffiths, D.
Grindley, H. E.
Harrison, J. R.
Hartley, J. J.
Hatch, H. B.
Haydon, R. H. S.
Henderson, F. Y.
Henderson, T.
Hogan, M. A.
Hudson, R. G. S.
Johnson, H. E.
Jones, T. B.
Kendrick, R. M.
Le Grand, J. P.
Lewis, H. P.
Little, O. H.
Littlehales, C. I.
McCormick, J.
McLintock, W. F. P.
Merrett, E. A.
Mizzi, L. F.
Murray, E. F. O.
Narke, G. G.
Nuttall, W. L. F.
Penney, F. M.
Perrott, B.
Pillar, J. E.
Prisk, R.
Pugh, W. J.
Raeburn, C.
Rao, M. V.
Rau, S. S.
Ridge, H. M.
Ritson, J. R.
Robertson, T.
Sadek, H.
Segnit, R. W.
Sikes, H. L.
Stanworth, J.
Thomas, R. H.
Thompson, Rev. J. C.
Trotter, F. M.
Turner, H. W.
Wadia, D. N.
Watkins, F. L.
Whitfield, T. W.
Williams, R. R.
Wilson, L. E.

Foreign Member Deceased.

Nathorst, Alfred Gabriel [elected in 1904].

Foreign Correspondent Resigned.

Lehmann, Prof. Johann [elected in 1892].

The following Personages were elected Foreign Members during the year 1921 :—

Dr. Frank Wigglesworth Clarke, of Washington (D.C.).
Prof. Emile Haug, of Paris.
Prof. Maurice Lugeon, of Lausanne.
Prof. Hans Schardt, of Zürich.
Dr. Jakob Johannes Sederholm, of Helsingfors.
Dr. Henry Stephens Washington, of Washington (D.C.).

The following Personages were elected Foreign Correspondents during the year 1921 :—

Prof. Lucien Cayeux, of Paris.
Dr. Maurice Cossmann, of Paris.
Prof. Henry de Dorlodot, of Louvain.
Dr. Henri Douvillé, of Paris.
Prof. Louis Duparc, of Geneva.
Prof. Johan Kiær, of Christiania.
Prof. Waldemar Lindgren, of Boston (Mass.).
Prof. John J. Stevenson, of New York City.

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Mr. R. D. Oldham, retiring from the office of President; to Mr. G. W. Lamplugh and Col. H. G. Lyons, retiring from the office of Vice-President (and also from the Council); to Dr. H. H. Thomas, retiring from the office of Secretary; and to Dr. J. V. Elsden, Prof. P. F. Kendall, and Lieut.-Col. Sir A. Henry McMahon, retiring from the Council.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS AND COUNCIL.—1922.

PRESIDENT.

Prof. A. C. Seward, Sc.D., F.R.S., F.L.S.

VICE-PRESIDENTS.

Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S.
Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.

SECRETARIES.

Walter Campbell Smith, M.C., M.A.
James Archibald Douglas, M.A., B.Sc.

FOREIGN SECRETARY.

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

TREASURER.

Robert Stansfield Herries, M.A.

COUNCIL.

Frederick Noel Ashcroft, M.A., F.C.S.
Francis Arthur Bather, M.A., D.Sc., F.R.S.
Prof. Percy George Hamnall Boswell, O.B.E., D.Sc.
Prof. William S. Boulton, D.Sc., Assoc.R.C.Sc.
Thomas Crosbee Cantrill, B.Sc.
James Archibald Douglas, M.A., B.Sc.
John Smith Flett, O.B.E., M.A., LL.D., D.Sc., M.B., F.R.S.
Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
John Frederick Norman Green, B.A.
Frederick Henry Hatch, O.B.E., Ph.D.
Robert Stansfield Herries, M.A.
Prof. Owen Thomas Jones, M.A., D.Sc.
William Bernard Robinson King, O.B.E., M.A.
Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
Prof. Sidney Hugh Reynolds, M.A., Sc.D.
Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.
Walter Campbell Smith, M.C., M.A.
Sir Aubrey Strahan, K.B.E., Sc.D., LL.D., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
Prof. William Whitehead Watts, M.A., Sc.D., LL.D., F.R.S.
Henry Woods, M.A., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1921.

Date of Election.	
1884.	Commendatore Prof. Giovanni Capellini, *Bologna.*
1886.	Prof. Gustav Tschermak, *Vienna.*
1891.	Prof. Charles Barrois, *Lille.*
1893.	Prof. Waldemar Christofer Brögger, *Christiania.*
1894.	Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1896.	Prof. Albert Heim, *Zürich.*
1897.	Dr. Hans Reusch, *Christiania.*
1898.	Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899.	Prof. Emanuel Kayser, *Munich.*
1899.	M. Ernest Van den Broeck, *Brussels.*
1900.	M. Gustave F. Dollfus, *Paris.*
1900.	Prof. Paul von Groth, *Munich.*
1901.	Dr. Alexander Petrovich Karpinsky, *Petrograd.*
1901.	Prof. Antoine François Alfred Lacroix, *Paris.*
1903.	Prof. Albrecht Penck, *Berlin.*
1903.	Prof. Anton Koch, *Budapest.*
1904.	Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905.	Prof. Louis Dollo, *Brussels.*
1907.	Dr. Emil Ernst August Tietze, *Vienna.*
1907.	Commendatore Prof. Arturo Issel, *Genoa.*
1908.	Prof. Bundjirô Kôtô, *Tokyo.*
1909.	Prof. Johan H. L. Vogt, *Trondhjem.*
1911.	Prof. Baron Gerard Jakob De Geer, *Stockholm.*
1911.	M. Emmanuel de Margerie, *Strasbourg.*
1912.	Prof. Marcellin Boule, *Paris.*
1913.	Prof. Johannes Walther, *Halle an der Saale.*
1914.	Prof. Friedrich Johann Becke, *Vienna.*
1914.	Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1914.	Prof. Franz Julius Lœwinson-Lessing, *Petrograd.*
1914.	Prof. Alexis Petrovich Pavlow, *Moscow.*
1914.	Prof. William Berryman Scott, *Princeton, N.J.* (*U.S.A.*).
1921.	Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1921.	Prof. Émile Haug, *Paris.*
1921.	Prof. Maurice Lugeon, *Lausanne.*
1921.	Prof. Hans Schardt, *Zürich.*
1921.	Dr. Jakob Johannes Sederholm, *Helsingfors.*
1921.	Dr. Henry Stephens Washington, *Washington, D.C.* (*U.S.A.*).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1921.

Date of Election.

1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Berlin.* (*Deceased.*)
1900. Prof. Federico Sacco, *Turin.*
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1909. Dr. Daniel de Cortázar, *Madrid.*
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*
1912. Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912. Baron Francis Nopcsa, *Vienna.*
1912. Prof. Karl Diener, *Vienna.*
1912. Prof. Fusakichi Omori, *Tokyo.*
1912. Prof. Ernst Heinrich Weinschenk, *Munich.* (*Deceased.*)
1913. Dr. Per Johan Holmquist, *Stockholm.*
1921. Prof. Lucien Cayeux, *Paris.*
1921. Dr. Maurice Cossmann, *Paris.*
1921. Prof. Henry de Dorlodot, *Louvain.*
1921. Dr. Henry Douvillé, *Paris.*
1921. Prof. Louis Duparc, *Geneva.*
1921. Prof. Johan Kiær, *Christiania.*
1921. Prof. Waldemar Lindgren, *Boston, Mass.* (*U.S.A.*).
1921. Prof. John J. Stevenson, *New York City* (*U.S.A.*).

[NOTE.—The Lists of Awards of Medals and Funds, up to the year 1907 inclusive, are published in the 'History of the Geological Society.']

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND,'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William B. Scott.
1911. Prof. Waldemar C. Brögger.
1912. Sir Lazarus Fletcher.
1913. The Rev. Osmond Fisher.
1914. Prof. John Edward Marr.
1915. Sir T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.
1917. Prof. A. F. A. Lacroix.
1918. Dr. Charles D. Walcott.
1919. Sir Aubrey Strahan.
1920. Prof. G. J. De Geer.
1921. { Dr. B. N. Peach. / Dr. John Horne.
1922. Dr. Alfred Harker.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1908. Dr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. R. Bullen Newton.
1915. Mr. Charles Bertie Wedd.
1916. Mr. William Bourke Wright.
1917. Prof. Percy G. H. Boswell.
1918. Mr. Albert Ernest Kitson.
1919. Dr. A. L. Du Toit.
1920. Mr. William B. R. King.
1921. Dr. Thomas O. Bosworth.
1922. Dr. Leonard J. Wills.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur P. Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William W. Watts.
1916. Dr. Robert Kidston.
1917. Dr. George F. Matthew.
1918. Mr. Joseph Burr Tyrrell.
1919. Miss Gertrude L. Elles.
1920. Dame E. M. R. Shakespear.
1921. Mr. Edgar Sterling Cobbold.
1922. Dr. John William Evans.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE

'MURCHISON GEOLOGICAL FUND.'

1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest E. L. Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell.
1917. Dr. William Mackie.
1918. Mr. Thomas Crook.
1919. Mrs. Eleanor Mary Reid.
1920. Dr. David Woolacott.
1921. Dr. Albert Gilligan.
1922. Mr. Herbert Bolton.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather.
Dr. Arthur Walton Rowe.
1912. Mr. Philip Lake.
1913. Mr. Sydney S. Buckman.
1914. Mr. Charles S. Middlemiss.
1915. Prof. Edmund J. Garwood.
1916. Dr. Charles W. Andrews.
1917. Dr. Wheelton Hind.
1918. Mr. Henry Woods.
1919. Dr. William Fraser Hume.
1920. Dr. Edward Greenly.
1921. M. E. de Margerie.
1922. Dr. Charles Davison.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1908. Prof. T. Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Prof. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.
1915. Mr. John Parkinson.
1915. Dr. Lewis Moysey.
1916. Mr. Martin A. C. Hinton.
1916. Mr. Alfred S. Kennard.
1917. Prof. A. Hubert Cox.
1917. Mr. Tressilian C. Nicholas.
1918. Mr. Vincent Charles Illing.
1918. Mr. William Kingdon Spencer.
1919. Mr. John Pringle.
1919. Dr. Stanley Smith.
1920. Dr. John D. Falconer.
1920. Mr. Ernest S. Pinfold.
1921. Dr. Herbert L. Hawkins.
1921. Mr. C. E. N. Bromehead.
1922. Mr. Arthur Macconochie.
1922. Mr. David Tait.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

Dr. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.
1915. Dr. Henry Hubert Hayden.
1917. Mr. Robert G. Carruthers.
1919. Sir Douglas Mawson.
1921. Dr. Lewis L. Fermor.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1909. Lady (John) Evans.
1912. Library extension.
1915. Prof. Émile Cartailhac.
1918. Sir William Boyd Dawkins.
1921. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1908. 'Grey-Wether' sarsens on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. Mr. Bernard Smith. Mr. John Brooke Scrivenor.
1915. Mr. Joseph G. Hamling.
1917. Mr. Henry Dewey.
1921. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE 'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1908. Mr. James A. Douglas.
1909. Dr. Alexander M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Prof. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Dr. John K. Charlesworth.
1917. Dr. Arthur Holmes.
1918. Mr. James A. Butterfield.
1920. Miss M. E. J. Chandler.
1920. Mr. L. Dudley Stamp.
1921. Mr. Ralph W. Segnit.
1921. Mr. Frederick S. Wallis.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions	157	10	0			
Admission-Fees, 1922	420	0	0			
				577	10	0
Arrears of Annual Contributions	130	0	0			
Annual Contributions, 1922	2100	0	0			
Annual Contributions in advance	90	0	0			
				2320	0	0
Quarterly Journal Subscriptions	220	0	0			
Record of Geol. Lit. Subscriptions	30	0	0			
				250	0	0
Sale of the Quarterly Journal, including Longmans' Account				400	0	0
Sale of other Publications				15	0	0
Miscellaneous Receipts				30	0	0
Interest on Deposit-Account				20	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s*. 7*d*. Natal 3 per cent. Stock.	8	0	0			
				351	16	0
Total Ordinary Income				£3964	6	0
Deficit				445	14	0
				£4410	0	0

the Year 1922.

EXPENDITURE ESTIMATED.

	£ s. d.	£ s. d.
Repairs and Maintenance Fund		200 0 0
House-Expenditure:		
Taxes & Fire-Insurance	25 0 0	
Electric Lighting and Maintenance	65 0 0	
Gas	40 0 0	
Fuel	60 0 0	
Annual Cleaning	25 0 0	
Washing and Sundry Expenses	70 0 0	
Tea at Meetings	30 0 0	
		315 0 0
Salaries and Wages, etc.		1450 0 0
Office-Expenditure:		
Stationery	60 0 0	
Miscellaneous Printing	130 0 0	
Postages and Sundry Expenses	100 0 0	
List of Fellows	100 0 0	
		390 0 0
Grant to Conjoint Board of Scientific Societies		10 0 0
Library (Books and Binding)	150 0 0	
(Catalogue Cards)	20 0 0	
		170 0 0
Publications:		
Quarterly Journal (Vol. lxxviii), including Commission on Sale	950 0 0	
Postage on Journal, Addressing, etc.	75 0 0	
Abstracts of Proceedings, including Postage	250 0 0	
Record of Geological Literature for 1921	150 0 0	
		1425 0 0
Total Ordinary Expenditure		£3960 0 0

Special Expenditure.

Compilation of Record of Geological Literature (1915–1919)		450 0 0
		£4410 0 0

ROBERT S. HERRIES, *Treasurer.*

January 27th, 1922.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1921:						
Current Account	289	7	6			
,, Balance in the hands of the Clerk at January 1st, 1921	20	4	9			
				309	12	3
,, Compositions				157	10	0
,, Admission-Fees:						
Arrears	163	16	0			
Current	283	10	0			
				447	6	0
,, Arrears of Annual Contributions				131	5	0
,, Annual Contributions for 1921:—						
Resident Fellows	2034	7	6			
,, Annual Contributions in advance	87	0	0			
				2121	7	6
,, Publications:						
Sale of Quarterly Journal:						
,, Vols. i to lxxvi (less Commission £10 5*s.* 11*d.*)	132	14	0			
,, Vol. lxxvii (less Commission £36 6*s.* 5*d.*)	204	19	3			
				337	13	3
,, Quarterly Journal Subscriptions				233	18	3
,, Other Publications (less Commission)				35	9	6
,, Miscellaneous Receipts				30	14	10
,, Interest on Deposit				22	5	0
,, Dividends, as received:—						
£2500 India 3 per cent. Stock	75	0	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	10	10	0			
£2250 London & North-Western Railway 4 per cent. Preference Stock......	63	0	0			
£2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	78	8	0			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	36	5	2			
£267 6*s.* 7*d.* Natal 3 per cent. Stock......	5	12	4			
£500 5 per cent. War Stock (1929–1947)	25	0	0			
				293	15	6
,, Income-Tax recovered				83	0	10
Special Receipts.						
To Transfer from Sorby & Hudleston Bequests.	171	15	0			
,, ,, ,, the Prestwich Fund	65	18	6			
,, ,, ,, the Barlow Jameson Fund ...	56	19	9			
				294	13	3
,, Sale of £500 5 per cent. War Stock 1929–1947 ...				438	5	3
				£4936	16	5

Year ended December 31st, 1921.

PAYMENTS.

	£ s. d.	£ s. d.
By Maintenance Fund		250 0 0
,, House-Expenditure :		
Taxes	15 0	
Fire- and other Insurance	24 16 7	
Electric Lighting and Maintenance	53 5 10	
Gas	36 2 4	
Fuel	39 19 6	
Furniture and Repairs	16 19 0	
House-Repairs and Maintenance	2 2 5	
Annual Cleaning	16 5 3	
Washing and Sundry Expenses	71 18 0	
Tea at Meetings	27 0 7	
		289 4 6
,, Salaries and Wages, etc. :		
Permanent Secretary	550 0 0	
Librarian	300 0 0	
Clerk	200 0 0	
Junior Assistant	104 0 0	
House-Porter and Wife	141 17 6	
Housemaid	79 2 0	
Charwoman and Occasional Assistance	30 11 0	
Accountants' Fee	10 10 0	
Extra Assistance	13 0 0	
		1429 0 6
,, Office-Expenditure :		
Stationery	54 16 9	
Miscellaneous Printing	150 6 4	
Postages and Sundry Expenses	114 3 11	
		319 7 0
,, Library (Books and Binding, etc.)		164 17 2
,, Library-Catalogue: Compilation		50 0 0
,, Publications :		
Quarterly Journal, Vol. lxxvii, Paper, Printing, and Illustrations	940 3 8	
Postage on Journal, Addressing, etc.	80 17 8	
Abstracts, including Postage	246 15 0	
List of Geological Literature	173 17 3	
		1441 13 7
,, Grant to the Conjoint Board of Scientific Societies (1920 & 1921)		20 10 0
Special Expenditure.		
By Quarterly Journal (parts 3 & 4 of Vol. lxxvi)	623 12 2	
,, Geological Literature, 1913	249 5 4	
,, ,, ,, , 1915–19, Compilation (on a/c)	25 0 0	
		897 17 6
By Balance in the hands of the Bankers at December 31st, 1921	71 3 9	
,, Balance in the hands of the Clerk at December 31st, 1921	3 2 5	
		74 6 2
		£4936 16 5

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

J. FREDK. N. GREEN, } *Auditors.*
R. M. DEELEY,

January 27th, 1922 ROBERT S. HERRIES *Treasurer.*

Statement of Trust-Funds and Special Funds: December 31st, 1921.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	32	3	8	By Cost of Medal	21	0	0
,, Dividends on the Fund invested in £1073 Hampshire County 3 per cent. Stock	32	3	8	,, Award from the Balance of the Fund	11	3	8
				,, Balance at the Bankers' at December 31st, 1921	32	3	8
	£64	7	4		£64	7	4

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	26	0	3	By Cost of Medal	1	5	0
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	28	0	2	,, Award to the Medallist	10	10	0
,, Income Tax recovered	12	0	2	,, Award from the Balance of the Fund	28	5	4
				,, Balance at the Bankers' at December 31st, 1921	26	0	3
	£66	0	7		£66	0	7

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	52	15	3	By Cost of Medal	1	9	0
,, Dividends on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	70	7	0	,, Award to the Medallist	25	0	0
				,, Awards from the Balance of the Fund	43	18	0
				,, Balance at the Bankers' at December 31st, 1921	52	15	3
	£123	2	3		£123	2	3

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	52	1	5	By Transfer to General Purposes Account	56	19	9
„ Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	9	16	8	„ Balance at the Bankers' at December 31st, 1921	9	2	6
„ Income Tax recovered	4	4	2				
	£66	2	3		£66	2	3

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	10	7	11	By Cost of Medal	12	12	0
„ Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	4	8	2	„ Balance at the Bankers' at December 31st, 1921	4	1	11
„ Income Tax recovered	1	17	10				
	£16	13	11		£16	13	11

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	73	5	4	By Grants	8	8	0
„ Dividends on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	4	3	4	„ Balance at the Bankers' at December 31st, 1921	70	1	0
„ Interest on Deposit	1	0	4				
	£78	9	0		£78	9	0

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	60	13	6	By Transfer to General Purposes Account	65	18	6
„ Dividends on the Fund invested in £700 India 3 per cent. Stock	21	0	0	„ Balance at the Bankers' at December 31st, 1921	15	15	0
	£81	13	6		£81	13	6

'Daniel-Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	15	11	8	By Awards	30	17	4
,, Dividends on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	30	11	4	,, Balance at the Bankers' at December 31st, 1921	15	5	8
	£46	3	0		£46	3	0

SPECIAL FUNDS.

Hudleston Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	44	10	10	By Transfer to General Purposes Account	85	17	6
,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	28	8	4	,, Balance at the Bankers' at December 31st, 1921: Current Account		17	0
,, Income Tax recovered	12	0	0				
,, Interest on Deposit	1	15	4				
	£86	14	6		£86	14	6

Sorby Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1921	44	10	10	By Transfer to General Purposes Account	85	17	6
,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	28	8	4	,, Balance at the Bankers' at December 31st, 1921: Current Account		17	0
,, Income Tax recovered	12	0	0				
,, Interest on Deposit	1	15	4				
	£86	14	6		£86	14	6

Maintenance Fund.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Transfer from General Purposes Account	250	0	0	By Payments during the year	116	16	2
,, Interest on Deposit	4	5	2	,, Balance at the Bankers' at December 31st, 1921	137	9	0
	£254	5	2		£254	5	2

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

ROBERT S. HERRIES, *Treasurer.*
January 27th, 1922.

J. FREDK. N. GREEN,
R. M. DEELEY, } *Auditors.*

Statement relating to the Society's Property.

December 31st, 1921.

	£	s.	d.	£	s	d.
Balance in the Bankers' hands, December 31st, 1921	71	3	9			
Balance in the Clerk's hands, December 31st, 1921	3	2	5			
				74	6	2
Balance of the Maintenance Fund	137	9	0			
Balance of the Sorby and Hudleston Funds	1	14	0			
				139	3	0
Arrears of Annual Contributions (Estimated to produce £130 0*s.* 0*d.*)				226	6	0
				£439	15	2
Funded Property, at cost price:—						
£2500 India 3 per cent. Stock	2623	19	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3			
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6			
£2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	3607	7	6			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0			
£2000 Canada $3\frac{1}{2}$ per cent. Stock (1930–1950)	1982	11	0			
				£13,716	2	9

[NOTE.—*The above amount does not include the value of the Library, Furniture, and stock of unsold Publications. The value of the Funded Property of the Society, at the prices ruling at the close of business on December 31st, 1921, amounted to* £7193 6*s.* 6*d.*]

ROBERT S. HERRIES, *Treasurer.*

January 27th, 1922.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Dr. Alfred Harker, F.R.S., the President addressed him as follows: —

Dr. Harker,—

From the first you have recognized, as you were among the first to realize, the necessity of combining field-work with laboratory research. Well qualified by your mathematical training to apply the laws of crystal optics and physical chemistry to petrological problems, your early work on the Bala volcanic series, the Shap granite, and Carrock Fell, established your position as a petrologist and field-geologist. Selected to the Geological Survey for the purpose of surveying portions of the Tertiary volcanic region of the West of Scotland, your ten years' service produced two important memoirs, on the Tertiary igneous rocks of Skye and on the Small Isles of Inverness-shire. In addition to these, and many other records of observations, your work has always been characterized by a breadth of view and a recognition of fundamental principles. Applying the results of physical chemistry to the differentiation of rock-magmas, you have indicated a manner in which a separation of the alkaline and calcic portions might be brought about, and you were the first to draw attention to the correspondence of the distribution of these types with areas characterized by the Atlantic and Pacific types of coast-line. Your work on the 'Natural History of Igneous Rocks' and your addresses to the British Association and to this Society have all been important contributions to theoretical geology. For these reasons the Council has accorded to you the Wollaston Medal, in recognition of those manifold services, by which you have advanced our knowledge of the mineral structure of the Earth, both in the narrower and in the more extended meaning of the words.

Dr. Harker replied in the following words :—

Mr. President,—

I wish to express my keen appreciation of the distinction which has been conferred upon me, and to record my thanks to the Council for their generous estimate of my merits. To so high an honour I have never ventured to aspire. If a perusal of the list of

former Wollaston Medallists left me with a lively sense of my own unworthiness, this feeling has at least been tempered by the kind congratulations of friends, and now by the graceful words with which you have accompanied the presentation.

The occasion is one which invites retrospect, and the personal note will perhaps be pardonable. Looking back, I acknowledge that the lines have fallen to me in pleasant places. I should be ungrateful were I to forget the constant support extended to me by my College, or the debt which I owe to Prof. Hughes, who first turned my steps into the paths of Geology. Gratefully too, I recall the encouragement which I have received from this Society, and from the comradeship of colleagues at Cambridge and many friends in London and Edinburgh. Much of my active life has been passed in teaching. If such occupation limits in some measure the time that can be given to private work, it still brings notable compensations. It is good, I think, to be brought back often to first principles, and to be braced by contact with younger and more ardent minds. You, Sir, have emphasized the value of field-work in conjunction with laboratory research. It was by the good offices of Sir Archibald Geikie that I have been enabled to enjoy this advantage also, and to acquire some experience of systematic mapping amid the delightful scenes of the West Highlands.

I wish I could believe that all these favours of fortune have been turned to the best account in the service of Geology, but I am conscious of many shortcomings. There remains the hope that some years of activity may still be left for me to justify, if I can, the honour now bestowed upon me.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Dr. John William Evans, F.R.S., addressing him as follows:—

Dr. Evans,—

Taking up the study of geology, originally from pure love of the subject, you have had an extensive, varied, and fruitful experience. In Western and Southern India and in South America you have conducted and controlled important geological investigations,

contributing largely by your own observations to, and by your writings to the dissemination of, the results; nor have you feared to attack the more abstruse and polemical problems of theoretical geology, of which you have been an eloquent illuminator and interesting exponent. To many, doubtless, this aspect of your activities looms largest, to the exclusion of the great amount of laborious and detailed work which you have devoted to observation in field and laboratory, and of the contributions which you have made to our knowledge of the origin of rocks, both igneous and sedimentary. It is this side of your activities which carried most weight with the Council in its decision to award to you the Murchison Medal of the Society, nor was it oblivious of the service which you have rendered to science, by the use of your influence, in initiating, extending, and guiding the conduct of geological investigations in the colonies and dependencies of the British realm. Not in one way only have you earned that recognition which it is a pleasure to convey to you in the name of the Society.

Dr. Evans replied in the following words:—

Mr. President,—

It is nearly a third of a century since Prof. Judd awarded to me a medal struck from the same die as that which I have just been so fortunate as to receive at your hands. The former was given as an encouragement to one who was commencing his geological career. This Medal, I trust, I can accept as an assurance that I have not entirely wasted the intervening years. If some may think that, in a life with many calls upon it, I have attempted too much and carried too little to completion, I would plead that I have learnt, as I could not otherwise have done, how vast are the problems which our science presents for solution, and have been enabled to assist the younger men, with whom I have come into contact in my College and Colonial Office work, to realize the wide field of research that lies open before them.

Award of the Lyell Medal.

In handing the Lyell Medal, awarded to Dr. Charles Davison, to Prof. W. W. Watts for transmission to the recipient, the President addressed him as follows:—

Professor Watts,—

The Council has awarded the Lyell Medal to Dr. Davison. Not unmindful of his contributions to observational geology, or of his contributions to the problems connected with the constitution and consolidation of the Earth, it has based this award mainly on his lifelong devotion to the study of earthquakes. Commencing at a time when he was almost alone, in this country, as a student of the subject, he has steadfastly accumulated a mass of detailed observations and critical discussion, which has very materially advanced our knowledge. His recognition of the duplex origin of certain earthquakes has been fruitful of result, and has been extended by others, until it is now a truism that the origin of an earthquake need not be from a single centre, but may be of a very complex and extended character. To a long list of published contributions to the study of earthquakes he has recently added, by the issue of a manual of that older branch of seismology, more especially connected with geology, in which the subject is handled in a lucid and philosophical manner. In recognition of these services the Council decided to award to him one of the medals at their disposal, and to select that which is associated with the memory of one who, in his time, did much to collect, disseminate, and extend the knowledge of earthquakes; and, in handing it to you for transmission to him, I may express a personal pleasure in the fact that almost the last act of my tenure of the Presidency should be the presentation of this award to one who has been known and valued, as co-operating in a line of research which has always had special interest to myself.

Prof. W. W. Watts expressed his regret that Dr. Davison was prevented by illness from receiving the Medal in person. He pointed out the appropriateness of the award of the Lyell Medal to one who had done so much to prove the uniformity of geological causes at the present day, and whose method of research was essentially Lyellian in character. He asked permission to communicate Dr. Davison's acknowledgment in his own words:—

'It is with no little regret that I find myself unable to be

present at the Anniversary Meeting, and I am writing to ask if you would be so kind as to represent me when the Lyell Medal is presented, and on my behalf to thank the President and Council for their award. It is one that, for several reasons, I value very highly, especially because the Medal was founded by the writer of the remarkable chapters on earthquakes in the "Principles of Geology," and not less because it is presented by the author of the report on the great earthquake of 1897. I should like to take this opportunity of saying that, whatever success my study of British earthquakes may have attained, is owing in great part to the help and encouragement which I constantly received from Prof. Charles Lapworth and from my old teacher, Prof. Lebour.'

CHARLES DAVISON.'

AWARD FROM THE WOLLASTON DONATION FUND.

The PRESIDENT then presented the Balance of the Proceeds of the Wollaston Donation Fund to Dr. LEONARD JOHNSTON WILLS, M.A., addressing him as follows:—

Dr. WILLS,—

Commencing your geological record with a study of the Lower Keuper rocks of Worcestershire, a study of the structure of the lower jaw of the Triassic Labyrinthodonts, and the discovery and description of the fossil plants at Bromsgrove, you have rendered more conspicuous service by your geological work on the Palæozoic rocks of North Wales and the Denbighshire coalfield, in the course of which you have developed important suggestions of tectonics, and added to our knowledge of the detailed stratigraphy of the region. Nor have more recent deposits been neglected, as is evidenced by your paper on late Glacial and post-Glacial changes in the Dee Valley, and on windworn pebbles in the high-level gravels of Bromsgrove. These studies you are still continuing, and we look forward to the early publication of some of your results. In recognition of the work done, and as an encouragement to future effort, the Council has awarded to you the balance of the Wollaston Fund, which I now hand to you in the name of the Society.

Award from the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Herbert Bolton, M.Sc., the President addressed him in the following words:—

Mr. Bolton,—

The Council has awarded to you the balance of the Murchison Fund, in recognition of your contributions to our knowledge of the stratigraphy and fauna of the Carboniferous System and of your continued and successful conduct of one of the most progressive of our provincial museums. As an authority on the insects of the Carboniferous Period you are conspicuous. The results of your labours, in the rescue, preservation, and description of these relics of a long-bygone past, have proved of supreme interest in establishing the great antiquity of some of the common insect-types of the present day. Added to this, your studies of the faunal stratigraphy of the Carboniferous rocks of the Bristol coalfield have been of value, which has led to their publication in our Quarterly Journal. For these reasons the Council has made this award to you, in recognition of the work which you have done in the past, and as an encouragement to others to emulate your example.

Award from the Lyell Geological Fund.

The President then handed the Balance of the Proceeds of the Lyell Geological Fund, awarded to Mr. Arthur Macconochie and to Mr. David Tait, to Dr. J. S. Flett for transmission to the recipients, addressing him as follows:—

Dr. Flett,—

The balance of the Lyell Fund has been awarded in two moieties to Mr. A. Macconochie and Mr. David Tait, in recognition of their joint and individual contributions to the advancement of geology. During his service as fossil-collector on the Geological Survey of Scotland, Mr. Macconochie was the discoverer of one of the most notable fossil localities in Scotland, where, at Glencartholm in Dumfriesshire, he found, in Lower Carboniferous shales, a large number of new genera and species of plants, crustaceans, fishes,

and land animals, and was the discoverer of the *Olenellus* fauna in the North-West Highlands, a discovery which caused the re-naming of two of the rock-groups of that region. Conjointly with Mr. Tait he collected a new fish-fauna from the Downtonian rocks of Lanarkshire, which, in the words of Dr. R. H. Traquair, opened out a new vista in the field of Palæozoic ichthyology. Mr. Tait, by his investigation of the Rhynie chert-band, was able to establish conclusively its true age as Old Red, and the investigation of his collections has thrown much light on the problems connected with this oldest land-flora. I have referred briefly to the more outstanding of their individual contributions to knowledge, made during a long and devoted service, which has yielded a large body of material for detailed investigation by others. In recognition of this, I ask you to accept and transmit these awards to their respective recipients in the name of the Geological Society of London.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT.

RICHARD DIXON OLDHAM, F.R.S.

By the death, on September 6th last, of HENRY WOODWARD, we lose a Fellow of standing and distinction, who was for long a regular attendant, and familiar figure, at our meetings. Born at Norwich on November 24th, 1832, son of Samuel Woodward, well known in his day as an antiquary and geologist, he was a naturalist by disposition from the beginning. After a varied experience in his earliest years, he was appointed an assistant in the Geological Department of the British Museum in 1858, an appointment which he retained, with promotion to Keeper in 1880, until his retirement in 1901. In 1864 he found a further outlet for his energy in the foundation of the 'Geological Magazine,' in conjunction with the late Prof. T. Rupert Jones, and was sole editor from the succeeding year until the end of 1918. In the November number of that Magazine will be found a notice of his published contributions to Palæontology and Geology, principally dealing with fossil Crustacea; by these he will probably be best known to our successors, but those who worked with him are aware that, however valuable they may be, by no means the least service which he rendered was the opportunity given for the publication of the work of others, by the conduct and continuance of the Magazine founded in 1864. Hardly a geologist of any standing but has at one time or another found in it a channel of publication, often in those early years when other avenues were still unopened. Under his editorship the Magazine has always welcomed the expression of novel interpretations of observation, even when at variance with opinions commonly accepted, and in this way, no less than by numerous records of original investigations, the Magazine has served geology well in the past, as doubtless it will continue to do in the future.

In the same year, 1864, he was elected a Fellow of our Society, and in the course of his Fellowship gave twenty-seven years to the Council, was three times Vice-President, and once President; his services were further recognized by the award, in succession, of the Wollaston and Lyell Funds, and of the Murchison and Wollaston Medals. He was elected a Fellow of the Royal Society in 1873, received the Honorary degree of LL.D. from the

University of St. Andrews in 1878, and had been President of the Palæontographical, Malacological, and Royal Microscopical Societies.

LOUIS COMPTON MIALL, who became a Fellow of the Society in 1875, was born at Bradford in 1842, and died on February 21st, 1921. He began his career as an elementary school-teacher, but was so much interested in natural science that he soon left his first profession for the curatorship of the Literary & Philosophical Society's Museum at Bradford, and afterwards for the curatorship of the more important corresponding Museum at Leeds. In 1876 he was elected Professor of Biology in the newly-founded Yorkshire College of Science, and he retained his Professorship in the University of Leeds, as it afterwards became, until his retirement from active work in 1907. In 1904–1905 he was also Fullerian Professor in the Royal Institution, London. Although an all-round naturalist, Miall was at first more especially interested in geology and palæontology, and he began original research with some experiments on the contortion of Carboniferous Limestone (Geol. Mag. 1869, p. 505). In 1869 he discovered in the Coal-Measures at Bradford a new Labyrinthodont, which was described as *Pholiderpeton scutigerum* by Huxley in the Quarterly Journal of the Geological Society for that year. Miall wrote a geological appendix to this description, and, when he presented it to the Society, he made the acquaintance both of Huxley and of Lyell. His interest in the little-known group of Labyrinthodonts was thus aroused, and in 1873–74 he prepared important reports on these fossils, with many new observations and conclusions, for the British Association. In 1874 he also published a paper on Labyrinthodont remains from the Trias of Warwick in the Society's Quarterly Journal. At the same time Miall studied closely the Palæozoic Ganoid fishes, and he gave to the Society an account of the palate of *Ctenodus* and the skull of *Rhizodus*. In 1884 he also contributed to the Quarterly Journal a valuable memoir on *Megalichthys*, which was afterwards published in an extended form by the Leeds Museum. In 1878 he began for the Palæontographical Society a Monograph of the Sirenoid and Crossopterygian Ganoids, but did not proceed further than the introduction and a description of *Ceratodus*. From 1881 onwards Miall gave increasing attention to existing rather than to fossil animals, and he made important contributions to our knowledge of the structure

and life-history of insects. After his retirement he also wrote a most interesting history of the progress of zoology. He was President of Section D (Zoology) of the British Association at Toronto in 1897, and of Section L (Education) at Dublin in 1908. The Proceeds of the Wollaston Donation Fund were awarded to him by the Geological Society in 1875; he was elected a Fellow of the Royal Society in 1892, and received the degree of D.Sc. from Leeds University in 1904. He was an inspiring teacher and charming friend, and his memory will always be treasured by those who knew him. [A. S. W.]

Dr. Marshman Edward Wadsworth was born at Livermore Falls (Maine) in 1847, where he spent the early years of his life upon his father's farm. He graduated at Bowdoin College in 1869, and subsequently became a student of science in Harvard University, receiving the degree of Ph.D. from that institution in 1879. From 1877 to 1887 he was closely associated with Prof. J. D. Whitney as assistant in the Geological Department. In 1884 and 1885 he visited many Universities in England and on the Continent, familiarizing himself with their organization and studying modern petrographical methods under Prof. H. Rosenbusch. He first appears as a contributor to American geology and petrology in the late seventies of the last century. Between the years 1879 and 1885 many papers from his pen were published in the Proceedings of the Boston Natural History Society, in the Bulletins of the Museum of Comparative Zoology of Harvard College and elsewhere, among which the following may be specially mentioned:—'On the Origin of the Iron-Ores of the Marquette District' (1880); 'On the Trachyte of Marblehead Neck' (1881); and 'Lithological Studies' (1884), an important quarto memoir of 266 pages with eight chromolithographic plates illustrating the microscopic features of certain meteorites and rocks. Before 1884 the only important work on microscopical petrography, published in America, was Zirkel's 'Report on the Rocks collected during the United States Geological Exploration of the Fortieth Parallel,' which appeared in 1876. Wadsworth's 'Lithological Studies' is therefore the first work of its kind written by an American. In this memoir, after dealing with the classification of rocks, their origin, their mode of alteration, and their relation to meteorites, he gives detailed descriptions of the macroscopic and microscopic characters of siderolites, pallasites, and peridotites.

In 1887 Dr. Wadsworth became President of the Michigan School of Mines, which was then in its infancy. He added to its equipment, organized courses of instruction, and made it in five years the greatest institution of its kind in the United States. From this time onwards he devoted himself mainly to administrative and teaching work. In 1907 he was appointed Dean of the School of Mines in Pittsburgh University, retiring in 1912 under the age limit. His services were much appreciated by the Faculty, and at the time of his death, which occurred on April 21st, 1921, he was Dean Emeritus, Professor of Mining Geology, and Emeritus Curator of Geological and Mineralogical Collections in that University. He was elected a Fellow of our Society in 1889.

[J. J. H. T.]

Frederic Richard Mallet, son of Robert Mallet, himself a distinguished member of our Society, joined the Geological Survey of India in February 1859. In his earlier years on the Survey he had a varied experience of field-work in the Himalayas, Central India, Assam, and Burma, but from 1876 until his retirement in 1889 was almost continuously in charge of the Museum and Laboratory of the Department. He was the author of numerous published contributions to our knowledge of geology, of which the most important were probably his Memoir on the Vindhyan System and his masterly description of the dormant Volcano of Barren Island in the Bay of Bengal; but not less valuable than his published papers, though less apparent, was the large amount of careful work which he devoted to the maintenance of the Survey collections and to the assistance of other members of the staff. Possessed in an eminent degree of precision and neatness of method, a retiring disposition, covering a consistent application to and thoroughness in his work, and an unfailing courtesy and kindliness of demeanour, he was always ready to help his fellow-workers in their difficulties, and won the attachment and esteem of all who came in contact with him. After his retirement from the Geological Survey of India he published little, but continued to devote himself to the pursuit of his favourite subject until advancing years deprived him of the power of continuing to work in his laboratory. He was elected into the Society in 1868, and passed away on June 24th of last year in the 81st year of his age.

Robert Logan Jack was a geologist of distinction, one of the pioneers of, and an extensive contributor to, Australian geology. Born in Ayrshire in 1845, he was educated at Edinburgh University, and joined the Geological Survey of Scotland in 1867. In 1877 he was appointed Government geologist for North Queensland, and in 1879 for the whole of the Colony. He surveyed and reported on the Bowen-River coalfield, and, in 1879–80, led the first expedition to traverse the eastern portion of the Cape-York Peninsula. This expedition gave him an opportunity of establishing his reputation as an intrepid and enterprising explorer; in spite of hardship, difficult weather, lack of food, and hostility of the natives, by whom he was speared through the shoulder, he carried the exploration to a successful conclusion. His next important exploration was of the western portion of the colony, where he recognized the structural conditions, and predicted the occurrence of artesian water in the plains of the arid regions, of the interior; this prediction led to successful boring, which has been extended until artesian wells are now numbered by thousands. In 1899 he resigned his appointment with the Queensland Government to undertake an exploration of the metalliferous deposits of Szechuan. Here adventure again dogged his footsteps, for he was caught and cut off from the coast by the Boxer rebellion, and had to make his escape westwards over the mountains to Burma. In 1901 he returned to London, and at the close of 1904 once more went back to Australia, where, in 1911, he was appointed Royal Commissioner on the Collie coalfield, and chairman of the Royal Commission to report on miners' lung diseases. Dr. Jack's published contributions to geology comprise 145 reports, during his service as Government geologist, as well as numerous books published independently. During the last three years of his life he was engaged on a critical review and correlation of the explorations which had been carried out during the last three centuries in and around Cape-York Peninsula. He was elected a Fellow of our Society in 1870, and was a member of the Council in 1903–1904. He died at Sydney in the early part of November, 1921.

By the death of the Earl of Ducie, P.C,, F.R.S., which took place on October 28th, 1921, at the age of 94, the Geological Society lost a member of very long standing, who was elected in 1853, and served on the Council as early as 1856–58. A man of varied activities and influence, having been a Member of the

House of Commons, Captain of the Yeomen of the Guard, Lord Warden of the Stannaries from 1888 to 1908, Lord Lieutenant of Gloucestershire and of the cities of Gloucester and Bristol from 1857 to 1911, and President of Bristol College since 1860, he had throughout retained a keen and practical interest in geology, though he did not attempt original work. He had an extensive collection, chiefly of local fossils, and was always ready to offer hospitality and facilities for investigation to anyone studying the rocks of the Tortworth area. [S. H. R.]

John Clarke Hawkshaw was educated at Westminster School and Cambridge, where, apart from distinction in his academical studies, he became Captain of the C.U.B.C. On leaving Cambridge he adopted the profession of civil engineer, which he pursued with distinction, and was President of the Institution of Civil Engineers in 1902; during the late war he commanded the Railway Transport Staff Corps and was made Hon. Colonel for his services. Outside his profession he took a keen interest in natural history and geology, and, besides important papers on engineering subjects, contributed to the Journals of the Linnean, and of our own, Society. He was elected a Fellow of this Society in 1866, and served on the Council in 1879–83 and 1891–92.

Thomas Lindsay Galloway came of a family of mining engineers, his father and two brothers all having attained eminence in the profession in which he himself achieved distinction. In his younger days he studied at Glasgow University under Lord Kelvin, by whom he was selected to carry out the testing of the piano-wire method of making deep-sea soundings. On his return from the voyage to Brazil, in which these tests were successfully carried out, he devoted himself to the study and afterwards to the practice of mining, and was connected with the Campbeltown Colliery as manager, and afterwards as director, from 1881 till his retirement a few years ago. Of a scholarly disposition and philosophical turn of mind, he had wide interests outside his profession, and took a prominent part in the foundation of the Archæological Society of Kintyre. He was elected a Fellow of this Society in 1876.

Sir William Edward Garforth was a mining engineer of distinction, whose name will be principally remembered in con-

nexion with his discovery of the influence of an admixture of shale-dust in preventing explosions in collieries, a discovery which has had a far-reaching effect in diminishing the dangers of coal-mining, and has led to the compulsory treatment of passages in mines with stone-dust, as a preventive of the spreading of explosions. He took interest in the design of helmets, by means of which rescue-parties might penetrate into poisonous atmospheres, giving freely from his private funds to the research. He had been President of the Mining Association of Great Britain, and of the Institution of Mining Engineers, and was knighted in 1914. He was elected a Fellow of our Society in 1891.

Henry Duckworth, coming of a family which attained distinction, one brother being the late Canon Duckworth, and another Sir Dyce Duckworth, Bart., F.R.C.P., was a Liverpool merchant who took a keen and active interest in geology. One of the founders, and the first President, of the Liverpool Geological Society, he contributed to the publications of that Society several papers, as the result of his observations and collections, on Perim Island in the Gulf of Cambay, in Egypt, Sicily, and the Somme Valley. He was elected a Fellow of this Society in 1858.

Henry Wemyss Feilden was born in 1838, son of Sir William Henry Feilden, second Baronet, of Feniscowles; he joined the Army, and served in the Indian Mutiny, the Chinese and South African wars, attaining the rank of Colonel, and receiving the C.B. for his military services. In 1875 he went out as naturalist with the British Polar Expedition, and travelled much on his own account, principally in the polar regions; to geology his principal contributions were his observation of the effects of ice-action in those northern regions, and especially his recognition of, and observations on, the action of floating ice in abrasion and transport. He was elected a Fellow of this Society in 1875.

George Clinch, born in 1860, was appointed to the library of the British Museum on leaving school; in 1895 he was made Clerk to the Society of Antiquaries, and in 1910 Librarian. Interested from his boyhood in archæology and the collection of flint-implements, he was the author of numerous papers on prehistoric archæology, and on the topography and sculpture of his native county, Kent, two of which were published in our Quarterly Journal. He was elected a Fellow of this Society in 1899.

The Rev. JOHN MORE GORDON, M.A., was born on April 13th, 1849. He entered as a theological student at Balliol College, Oxford, and graduated in 1873, winning the Ellerton Essay Prize in that year, and the Denyer Johnson Scholarship in 1875, in which year he was ordained. He was for 31 years vicar of St. John the Evangelist, Redhill. Although he has published none of his work, he was a very keen student of petrology and mineralogy, and formed a very fine collection of minerals (the specimens from Swiss localities being particularly fine). His gifts of minerals have much enriched the collections, both at the Natural History Museum and in the Geological Department of the University of Aberdeen, in which University his grandfather was Professor of Ecclesiastical History. His interest in science was very wide. He was a Fellow of the Physical Society and of the Royal Microscopical Society, a Member of the Mineralogical Society and of the Alpine Club. He was elected a Fellow of our own Society in 1888, and died at his London house on January 18th, 1922. [W. C. S.]

FREDERIC THOMAS MAIDWELL was born at Gunnerside, in Swaledale, in 1872. He qualified as an instructor in handicraft, and, after acting as such in the Midlands, received in 1908 an appointment under the Education authority of Runcorn, where he rendered useful service to the town and was a member of the Free Library Committee. Devoting the greater part of his life to geology, he was indefatigable in observing and recording particulars of sections, and gave special attention to the study of fossil footprints in the Trias. He was elected a Fellow of this Society in 1919.

CHARLES FERDINAND ZABEL was a young man of great promise, who, after a brilliant course of studentship, was employed on various mining investigations. At the outbreak of the late war he was engaged on a survey of manganese-deposits in the Rhine valley, and, with many others, was interned at Ruhleben, where he distinguished himself by his exertions for the welfare of his fellow-prisoners, and ably maintained the honour of the country to which he owed allegiance. Always keen in his interest for geology and our Society, his books have been presented to our Library and have given us some useful additions. He was elected a Fellow in 1919, and died at Tete, in East Africa, on July 15th of last year.

Ernst Heinrich Oskar Kasimir Weinschenk was born on April 6th, 1865, at Esslingen in Würtemberg. He was first Privatdozent and afterwards for many years Professor of Petrography in the University of Munich. He published numerous memoirs on mineralogy and petrology, but his most distinctive researches were on the subject of the mode of occurrence and genesis of graphite, in the course of which he contributed important additions to our knowledge of the deposits of Bavaria, Bohemia, and the Alps, as well as Ceylon. He was also especially interested in rocks and minerals rich in magnesia. He is best known, however, for his text-books on petrology, which are clearly written and well illustrated. The 'Introduction to the Petrological Microscope' and the 'Rock-forming Minerals' have been translated into English by R. W. Clark. He also published the 'Principles of Petrology' in two volumes, a general and a special part. The former is a masterpiece of lucid exposition. The views expressed are sound and at the same time show considerable originality. The work has been translated into English by Johannsen. He was elected a Foreign Correspondent of the Society in 1912, and died in 1921. [J. W. E.]

Although he was never a Fellow of our Society, it would be impossible to pass without mention the name of one so well known to geologists as Benjamin Harrison. Born in 1837, second son of a grocer at Ightham in Kent, a business which had been in the family for 150 years, and was afterwards inherited and carried on by him, he early developed a taste for geology and collecting fossils, and maintained his interest and zeal to the last. He first attracted attention by the identification of Roman remains at Ightham, and, shortly after, his attention was drawn to flint implements by the discovery of these relics of ancient man at Abbeville, and the controversy which arose therefrom. This led him to collect similar remains in his own district, of which he amassed a large collection, and made him known to men of eminence in that branch of knowledge. With Lord Avebury, Prof. Prestwich, and Sir John Evans he corresponded, and by them he was encouraged in his investigations. An indefatigable explorer of his district, of which he had an unrivalled knowledge, his memory will live mainly by his discovery of 'eoliths,' and the controversy which raged over the reality of the human origin of these alleged evidences of human activity in long-past ages. His services to Geology were recognized by the award of the Wollaston Fund in 1899.

For assistance in preparing these notices I have to express my obligation to Sir Jethro J. H. Teall, Dr. A. Smith Woodward, Prof. S. H. Reynolds, Mr. W. Campbell Smith, and many others who have been good enough to furnish information in reply to enquiries.

After announcing the election of Officers, the retiring President said:—

Two years have now elapsed since you elected me to the office of President; they have been eventful years in the history of the Society. When I assumed office your Council was faced with a very serious state of affairs brought about by the war, expenses had greatly increased, while income remained but little altered, and it almost seemed that we should have to face the alternative of either abandoning our Library, or of suspending our Journal. It was necessary to overhaul the whole of the affairs of the Society, to impose certain additional charges on the Fellows and to restrict some of the benefits which they had been enjoying, before that equilibrium between income and expenditure could be established, without which our continued existence as a Society would be impossible. As a result, we have been able to continue the two most important functions of the Society, the maintenance of a working library, and the publication of research, though we have been compelled to restrict our activities in other directions. Much has been done, yet the task is not complete; the axe has been wielded, I think sufficiently, but there is still work for the pruning hook on minor economies, insignificant separately but collectively appreciable. Of this your Officers are fully aware, and you may be confident that the matter will be borne in mind and attended to. It is not to be expected that all the action which your Council has taken during the last two years should receive unanimous approval; but, taken as a whole, I think that we may justly be unashamed of the record: it is not the work of any one man, it has only been possible by the co-operation of the whole body of the Officers and Council, of the Fellows at large, and of the permanent staff. I now hand over the care of the interests of the Society to a successor who will maintain its honour and dignity, and in relinquishing office I wish to render my thanks to all those who during the past two years have helped me in what has been an anxious and responsible, but far from thankless, task.

The Cause and Character of Earthquakes.

The study of earthquakes having always been recognized as one of the departments of Geology, no excuse is needed for devoting my address, on this occasion, to a review of the present state of our knowledge of the cause and character of earthquakes, using that word in the restricted, and original, sense of the disturbance of the ground which is sensible to human feelings, which causes alarm and destruction, and is properly that seism of the ancient Greeks, from which our modern term seismology is derived. This explanation is necessary, for, of late years, seismology has been extended to the study of a phenomenon of different character, the long-distance records of disturbances, only to be detected by very sensitive instruments of special construction; in some cases these are clearly connected with great earthquakes—as the word is here used—and by inference have been presumed to be so in all cases, even when there is no independent evidence of the earthquake proper. The records, regarded as records of the progressive enfeeblement of the larger disturbance of the true earthquake, would represent the cryptoseism, or unfelt earthquake, and be correctly described in the observatory records as earthquakes. That they are correctly so described is indisputable, if the word is taken in its literal interpretation as a quaking, however feeble, of the earth; but, if the implication is added that they have the same origin as the greater disturbance, the correctness of the description becomes doubtful. In presenting to you, some dozen years ago, the results of a study of the records of the Californian earthquake of 1906, I pointed out that, although the immediate origin of the earthquake proper might be traced to occurrences which took place in the outermost parts of the Earth's crust, these were but the secondary result of a deep-seated origin, or bathyseism, which gave rise, at the same time, to the disturbance which was recorded at long distances by suitable instruments. Later work and research has more and more confirmed both the correctness of this interpretation and the conclusion that the proximate cause of great and destructive earthquakes is distinct from that of the long-distance records, although the two origins are connected with each other as effect and cause.

In the present state of our ignorance of the nature of the bathyseism, it is difficult to give a clear and precise definition

of the connexion between it and the earthquake proper: the subject is an interesting one, and a review of the evidence, together with the deductions which can be drawn from it, would fill the time available; but it is not my intention to do more than to attempt, by analogy, to illustrate and explain the nature of the connexion of the bathyseism with its two independent results.

Not many years have passed since, in the south-eastern corner of England, we heard what were known as the guns of Flanders; and the description was correct. The sound—it was more a sensation than a sound—which was heard in Kent and Sussex was undoubtedly produced by the report of great guns, by the explosion, that is, of the charge in the gun itself; but, had the explosion done no more than give rise to the sound-waves which travelled far in every direction, it would have little troubled the enemy. Simultaneously, however, with the production of the report, and by the same explosion, a projectile was sent flying through the air, and, after a trajectory of some miles, itself exploded, causing the damage which was the purpose of its despatch. The effect of this second explosion was severe but local, and at a short distance away neither sound nor shock was sensible.

Here we have a very complete analogy, the explosion of the gun represents the bathyseism; the report and sound-waves, travelling afar, correspond to the disturbance which, propagated through the substance of the Earth, gives rise to the long-distance records; the explosion of the shell to those dislocations in the outer crust which produce the destructive earthquake; and the trajectory to the connexion, of which the character is as yet unknown, between the bathyseism and the surface-shock.

If this interpretation be accepted, it becomes evident that the distant records represent something which is distinct from the earthquake, as originally understood, and that the study of them, with the deductions drawn from that study, have little or no bearing on the problems of geology, as we usually limit the scope of that science. It is otherwise with the earthquake proper; originating in, and affecting, the outermost crust of the Earth, it has long, and rightly, been regarded as one of the departments of geology, both as regards cause and character, and it is with this aspect of the subject alone that I shall deal.

The character of earthquakes is known to an extent sufficient for my purpose; they are elastic waves, transmitted through the

substance of the Earth, not, as was once supposed, merely waves of elastic compression, but of most complicated character, and in all but a small minority of cases nothing but this vibratory movement, the orchesis, can be recognized. Occasionally, however, and only in the case of some earthquakes of destructive violence, there is also a bodily and permanent displacement of the solid ground, and this mass, or molar, movement has been distinguished as the mochleusis of the earthquake, as distinct from the elastic displacement, accompanied by return to the original position, which constitutes the orchesis. Now, the elastic waves can only be initiated by some sudden impulse or disturbance, such as might be produced by the fracture of rock; and as, in those earthquakes where mochleusis can be recognized, there is usually evidence of sudden movement along some pre-existent fault-plane, or of rending and fissuring of the solid rock, faulting or fracturing has come to be regarded as the cause from which the vibratory disturbance originates.

This conclusion is supported by the fact that the proximate origin of the shock can almost always be placed at a moderate depth from the surface. It is, unfortunately, impossible to give any precise figures, for none of the methods which have been suggested for determining the depth of the origin can be trusted, some because they depend on assumptions which the progress of knowledge has shown to be erroneous, others because they demand data which cannot be supplied with the requisite precision, if at all; but there is another way in which some idea of the depth of origin may be reached, based on the fact that there is almost invariably a well-defined area of maximum intensity of shock, surrounded by regions of diminishing intensity, as the distance from the central area increases. Since the violence of the disturbance will decrease with the increase of distance from the origin, it follows that the nearer the origin lies to the surface, the more closely does the variation of surface-distance from the epicentre approximate to the variation in actual distance from the origin; hence it is evident that the rate of variation of intensity of the disturbance will give some notion of the depth of the origin. In this way, quite apart from any numerical estimates which have been made, it becomes clear that, excluding a small minority of earthquakes which will be referred to later, the origin lies at a very moderate depth below the surface, probably seldom over 10 miles, and usually less. This places the origin within the limits of

the solid outer crust of the Earth, and in this region it is difficult to conceive of any cause, sufficient to originate the elastic wave-motion of the earthquake, other than the sudden fracture of the solid rock, where strain has outgrown the power of resistance.

Apart from this general reasoning from observation, there are cases on record where considerable displacements of the ground have been measured by the comparison of careful and accurate surveys made before and after the earthquake. In three of these, the Cutch earthquake of 1819, the Sumatran of 1892, and the Californian of 1906, the largest movements took place close to the line of fracture, and in opposite directions on opposite sides of it, the displacements decreasing on either side till a region was reached in which no change from the condition before the earthquakes could be recognized. As this is precisely what would take place if a solid body, capable of elastic deformation, was strained until fracture took place, the conclusion is justifiable that such was in fact the origin of the dislocation and displacements.

To this general rule there are some recognized exceptions. Quakings of the earth, identical in character with the true earthquake, may be caused by natural rockfalls, or artificially by explosions; and there is the class of volcanic earthquakes, recognized as due to disturbances directly connected with volcanic activity, though it is probable that the majority of volcanic earthquakes are in reality originated by rock-fracture and, therefore, only indirectly the result of volcanic activity. To these may, perhaps, be added earthquakes which are due to the direct transmission of elastic wave-motion from the bathyseism; but, when all these allowances are made, it must be admitted that, speaking generally, the immediate cause of earthquakes is the development of a state of strain in the outer rocky crust of the Earth, of such magnitude as to give rise to fracture, accompanied or not by displacement of the opposite sides.

So far the conclusions, which may be drawn from observation as they have been briefly outlined, belong rather to the domain of physics than of geology; but, when we go on to consider the cause to which the strain is to be attributed, and more especially the rate of growth, we are brought into contact with problems and deductions which are intimately connected with geology proper, and to which I propose to confine attention in the remainder of this address. As regards cause; this is usually attributed to what are known as the *tectonic processes*, a term which has never been

defined and is incapable of precise definition, but may approximately be described as the processes by which the folding and faulting of rocks were produced, and, in accordance with this attribution, the class of earthquakes, with which we are concerned, is referred to as tectonic. The rate of growth of strain has almost invariably been accepted as very slow, yet, when the subject is looked into, it will be found that there is really no evidence to support the acceptance; in part, it must be attributed to the general belief that all geological action is necessarily slow, and in part to the conclusion, forced on us in the latter days of the last century, that the Earth is a solid, inert, and highly-heated body, cooling slowly by radiation, with the subsidiary deduction that all deformation of the outer crust must be referred to contraction, consequent on that slow cooling. The latter of these reasons is now abandoned by those who forced it on us, and the former, though true in general, must not be treated as an unchangeable law, for there are many cases where a process, slow on the average, and as a rule, is occasionally subject to a temporary acceleration of rate. The evidence, too, which has been regarded as confirmatory of the slow growth of strain, may more properly be described as an interpretation of observed facts in accordance with an hypothesis.

In the report on the Californian earthquake of 1906, for instance, the displacements caused by that earthquake, and an earlier one in 1868, are discussed, and the conclusion is drawn that they should be explained by a slow growth of strain, extending over a century or so, partly relieved by fracture in 1868, and again in 1906. The argument is conclusive, in so far as it shows that the effects are consistent with the hypothesis; but it was not noticed that they would be equally consistent with a condition of quiescence throughout the whole period, with the exception of two short intervals immediately preceding the two shocks, respectively. The same may be said of all the supposed evidence in favour of a slow growth of strain; the after-effects may satisfactorily establish the conclusion that the proximate cause is fracture resulting from excessive strain, but they can give no indication of the time occupied in preparation. The earthquake comes and passes, it leaves certain records behind it; but these records would be the same, whether the preparatory growth of strain was secular or instantaneous in duration.

Yet the problem is not insoluble, for there is another line of attack, which has only become practicable within the last few years. If we regard the growth of strain as continuous, there will

be a certain increment which will lead to fracture, earthquake, and partial relief; then with a further increment the process will be repeated, and so we reach the concept of a mean strain-interval for each shock, which may be regarded as constant, on the average, for any given region, provided that the average is taken over long enough a period. If, then, we divide the mean increment of strain in a unit period of time by the mean number of shocks occurring in the same period, we obtain a fraction which represents the mean stress-interval for each shock, a fraction which should remain constant in the region under consideration; and from this it results that any variation in the rate of growth of strain must be accompanied by a corresponding variation in the frequency of earthquakes. We have, then, four quantities so inter-related with each other that, if three of them were known, the fourth can be determined. Two of these, namely, the mean frequency and the variation from that mean in any chosen period, can be obtained from observation; and, if the variation from the mean rate of growth of strain is also known for the selected portion of the whole period, that mean rate, which is the object of search can be obtained by a simple rule-of-three sum.[1]

The frequency of earthquakes is known to be subject to great variation from time to time, and this variation indicates a corresponding change in the rate of growth of strain. In the main, this change may, and probably must, be attributed to causes acting within the Earth, and directly related to the changes or processes by which the strain is produced; but it is evident that, if there were any external cause, which acted periodically and alternately in increase and decrease of the rate of growth of strain, and if it were possible to disentangle the variations due to this from those due to other causes, we should possess the means of framing a numerical estimate of the general rate of growth of strain.

One such cause of periodic variation is to be found in the tide-

[1] The argument may be put in a different form, simpler and more easily intelligible to some. If S represent the mean increment of strain in a given period and N the mean number of earthquakes recorded in the same period, then S/N is the fraction representing the mean strain-interval corresponding to an earthquake. If the variation of the growth of strain in any particular period is represented by v and that of the number of earthquakes by d, we get the equation

$$S \div N = (S \pm v) \div (N \pm d)$$

where

$$d = v/S$$

whence we obtain the simple ratio

$$d : N :: v : S.$$

producing stresses set up by the sun and the moon. It is true that many attempts have been made at different times to detect some connexion between the frequency of earthquakes and the position of the moon, and that no such connexion has yet been established, but these attempts have all been based on very imperfect records. In time it may, perhaps, be possible to apply to an earthquake record that method of harmonic analysis which has proved so fertile in the case of the ocean tides, but the day is long distant when a record of sufficient completeness will be available. Meanwhile, there are some simpler relations, of which a discussion is feasible, and the most promising of these seems to depend on the fact that the downward pressure is greatest at the time when the attracting body is on the horizon, and least when it is on the meridian. If, then, we divide an earthquake record into two groups, one containing all shocks which occur within six hours before a meridian passage, and the other all that happened within six hours after, the first of the two groups will cover a period during which the downward pressure is, on the average, increasing, while the other will cover a period during which it is decreasing. As the amount of the change so introduced is known, with sufficient accuracy for the present purpose, and as it must, on the hypothesis being used, influence the frequency of earthquakes, it follows that we have here a method which should enable us to make an estimate of the rate of growth of the strain to which fracture is due.

Although simple in principle, the method is difficult in application. To begin with, a record is required, of sufficient extent and continuity to give a trustworthy average, not merely of the general frequency, but also of the frequency in each of the two sections into which it is divided; and this means that the record must contain at least two thousand shocks and ought to contain double that number or more. Then it must be reasonably accurate as to times and complete as to occurrences, or at least must be fairly uniform in its incompleteness over the whole period investigated. There are not many records which fulfil these primary requirements, but there is another even more important. In all records there is a noticeable variation in frequency at different times of the day; moreover, the nature of this diurnal variation has been found to vary in different regions, but appears to be constant and characteristic in each region over the period of record. The cause of this periodicity may be reasonably attributed to some effect, meteorological or other, connected with the daily course of the sun; but its nature, no less than its variability,

shows that it cannot be attributed to gravitational attraction. It is only, therefore, by a conversion of the record from solar to lunar times that the influences of these other effects can be eliminated, and the gravitational attraction of the moon be detected and estimated, and, for the satisfactory application of this method, it is necessary that the record should cover a complete lunar cycle, or a period of nineteen years. There are only two records extant, and available, which fulfil this requirement, and of these the Italian is not only the most complete and accurate, but is the only one to which the conversion into lunar times has been applied.

A summary of the figures obtained has been published in our Quarterly Journal,[1] and from this we find that in the six hours preceding a meridian passage there were 3337 shocks, and in the six hours succeeding only 3270, giving a mean departure, from the general average for six lunar hours, of 33·5, or almost exactly 1 per cent. of the mean. So small a variation from perfect equality is well within the limit of what might reasonably be expected, if it were purely fortuitous and the stresses set up by the attraction of the moon had no effect whatever. This point will be returned to later on, but it will be useful to see what conclusions may be drawn if the variation is accepted as real, and due to the cause under consideration. The first of these is that the main stress, to which the strain is due, is of a compressive nature, consequent on an increase of downward pressure, or a removal of support from below. The second is that the vertical component of the general increase of strain amounts to just 100 times the variation of the corresponding component of the gravitational stress set up by the moon. It has been established by mathematicians that the maximum upward stress set up by the moon, at the points on the surface of the Earth where it is in the zenith or nadir, amounts to 1/8,450,000 of the Earth's force of gravity, and where it is on the horizon there is a downward stress of just one half of this: the total variation of downward pressure is, therefore, equivalent to a change of about 1/5,630,000 of that due to terrestrial gravitation, as between the points and times when the moon is on the horizon, or at the zenith or nadir. But the moon could never be directly overhead in any part of Italy, and a computation of the mean range of variation, over the whole period and the whole area concerned, reduces this fraction to about 1/9,400,000. As the

[1] Vol. lxxvii (1921) p. 2.

general increase of stress is 100 times this figure we get the result that the rate of increase of strain is equivalent to that which would be produced by an increase of downward pressure, or a corresponding reduction in the support of the crust, at the rate of 1/94,000 of that due to gravity, in each period of six hours.

It has long been established that the strength of the crust is far from being able to withstand the crushing strains which would be set up by removal of support from below, and the estimates, which have been independently made by different investigators, concur in putting the limit of the removal of support, which would result in crushing, where an area comparable with Italy is concerned, at not more than about 1/400 of the force of gravity. If this fraction is divided by that obtained in the previous paragraph we get the result that, starting from a condition of no strain, fracture would come about after an interval of 235 periods of six hours, or not quite 59 days. The calculation, therefore, indicates that the rate of growth of strain in Italy has been, on the average, such that the breaking point would be reached in about two months from start, with a wide variation on either side. Some other relations between the frequency of earthquakes and the diurnal variation of the tidal stresses might be, and have been, investigated; none of them seem so appropriate as that which has been detailed, and all give fairly confirmatory results, the longest period indicated, as required for reaching the breaking strain, being just about a year.

It must not be supposed that value can be attached to the precise figures. As is invariably the case, in all calculations regarding physics of the Earth, many considerations are involved of a very uncertain nature; but the reasoning does show that the increase of strain must have taken place at such a rate that the breaking point was reached in a period measurable at most by months. They prove conclusively that the period could not have been of such length as to be measurable by years or decades, for, had this been the case, the disparity dealt with would have been much greater than that actually found.

The same conclusion may be reached in another way. The stress-difference required to produce fracture in average hard rocks, as they are met with at the surface, is round about 1,000,000 grammes per centimetre square, and, allowing for the greater strength at depth which is indicated by the experiments of Prof. Adams and the computations of Prof. Burrell, we may put the breaking strength of the Earth's crust at about double of this, so

that, in order to reach this point in one year from starting, the strain would have to increase at the rate of about 1400 grammes per centimetre square in each quarter of a day. According to the late Sir George Darwin the stress-differences set up by the moon in the latitude of Italy would amount to about 20 grammes per centimetre square in an incompressible Earth, and in a compressible Earth with an incompressible crust—a condition much more akin to what we have reason to suppose is the reality—the stress-differences would be many times this figure [1]; but even the lower amount is nearly $1\frac{1}{2}$ per cent. of the growth required to reach breaking point in one year, it would be close on 15 per cent. if the period is increased to ten years, and, with anything approaching this proportion, a periodicity would result, which could not have escaped detection before now.

The figures, therefore, give us a lower limit of the rate of growth of strain, it must have been something faster than that needed to reach the breaking point in one year from starting, if the differences on which the argument is based are real. But are they real? The actual amount of difference, barely ·1 per cent. of the mean, is so small that it may well be fortuitous, and the true interpretation may be that the gravitational stresses, and the stress-differences produced by them, have no effect whatever in determining the time of occurrence of an earthquake. If this be so, then the rate of growth of strain becomes infinite, and each earthquake becomes the result of a rapid development of strain, akin to an explosion in its suddenness.

The truth may lie anywhere and must lie somewhere between these extremes, and so we reach the conclusion that there is no support for the commonly-accepted notion of a continuous, slow growth of strain, extending over years, decades, or even centuries, before the breaking point is reached. On the contrary, it appears that the cause of earthquakes is a rapid growth of strain. This strain cannot be developed without some deformation, but the magnitude of this has no relation to the frequency or magnitude of the earthquake; if change of form is slow and prolonged, relief may be provided by gradual yielding, if rapid, a very small amount of distortion may lead to fracture, and on the extent, form, and position of this fracture will depend the character of the resulting earthquake.

This study of the growth of strain leads on to the question,

[1] Sir G. H. Darwin, Scientific Papers, vol. ii (1908) p. 502; and Phil. Trans. Roy. Soc. vol. clxxiii (1882) pp. 219 *et seqq.*

which is the really important one in its bearing on geology, of how the strain is produced. It can hardly be the result of those tectonic processes which result in folding, for these must necessarily be slow in their action; the change of form involved in the bending of solid rock from its original shape into complicated folds, without breach of continuity, can only have been a slow one, and, as we have seen, the deformation which produces earthquakes must be a rapid one. With faults the case is different; many earthquakes are known to have been accompanied by movement along pre-existing fault-planes, in others the origin evidently agrees in position with known faults, and in all of these the distribution of the intensity of disturbance is closely correlated with the faults, being greatest in proximity to them and decreasing as the distance becomes greater. So much is indisputable, yet, despite a general acceptance of the explanation, that the earthquake was a result of the same process as that which gave rise to the formation of the fault, it must be recognized that the proof is not logically complete, for it might be that the cause and processes which gave rise to the earthquake were wholly different from, and independent of, that which produced the fault, the only connexion being that the weakness, resulting from the fault-fracture, served to localize the yielding, and so controlled the distribution and intensity of the earthquake. In a study of the Californian earthquake of 1906, where the greatest intensity of disturbance ranged along the line of the San Andreas fault, and was accompanied by considerable displacement and distortion of the surface along the fault-line, I was able to show that the ultimate cause of the earthquake was quite distinct from that which produced the fault, and that the fault was not the cause of the earthquake, nor the earthquake an incident in the formation of the fault.

In support of the supposition that earthquakes are not produced by, or at any rate are not necessarily the product of, the tectonic processes which have given rise to the displacements in faults, may be instanced the fact that in some cases of minor earthquakes, where it has been possible to fix the position of the epicentre with a close approach to definiteness, it has been found that surface examination gives no indication of the presence of a fault. This, however, is not conclusive, for there might have been a deep-seated, incipient, fault which had not yet extended to the surface, and so could not be recognized by geological survey.

Much more weighty and suggestive evidence is to be derived

from the great earthquakes which have been studied in detail. Reference has already been made to the Californian earthquake of 1906, and the conclusion drawn in that case is more fully exemplified by the Indian earthquake of 1897. Here there was no single leading fault and zone of maximum intensity of shock, but a complicated network of lines of extreme destructiveness, ramifying over an area not much different from that of England, and extending right across a series of great tectonic features, across the great monocline of the southern face of the Assam range, across that range itself, across the alluvial plain of the Brahmaputra Valley, the great boundary-faults of the Himalayas, and probably even across the main axis of elevation of the range.

A still more instructive instance is the Charleston earthquake of 1886. Here, in a region as devoid of any great structural feature, either of folding or faulting, and as little subject to earthquakes, as could be found in our own country, there suddenly occurred a great earthquake, of destructive violence in the central area and felt over an area measuring about 1500 miles across. It was an earthquake of first-class magnitude, whether we regard the maximum violence of shock or the extent of area affected, yet there is nothing in the structure of the surface-rocks to suggest that its origin was due to any tectonic process, and equally nothing which could lead to its classification as volcanic; and, if we accept the conclusions of Col. Harböe, regarding the character and extent of earthquake origins, the absence of any connexion, between the origin of the earthquake and the tectonics of the surface-rocks, becomes absolute, for, according to this interpretation, the origin becomes almost co-extensive with the seismic area, and the diminution of violence in the outer portions is not solely due to enfeeblement, resulting from the elastic propagation of the earthquake wave, but very largely to a diminution in magnitude of the originating impulse.

Whether this explanation be accepted or not, it must be conceded that, as regards the two earthquakes particularly referred to, of Charleston in 1886 and India in 1897, Col. Harböe's conclusions are not only supported by the particular facts on which they were based, but are in better accord with a number of peculiarities in the local variation of violence of the shock, and of other phenomena recorded, than is the current notion of a central focus of comparatively restricted dimensions. It accords also with those great earthquakes which, like the Calabrian earthquakes of the present century, had more than one centre of maximum intensity, connected by regions of less violence of shock.

These are some of the considerations which have led me to believe that Col. Harböe's interpretation is, in the main, well founded, and if it be true that earthquakes of great extent are due to systems of fracture, or analogous disturbance, ramifying over, and practically co-extensive with, the seismic areas of the earthquakes, that is, over areas of which the dimensions in any direction may be measured in hundreds of miles, it becomes more than ever necessary to recognize that the earthquake origins cannot be the result of processes and displacements, recorded, and indicated, by the tectonics of the surface-rocks. The real and ultimate origin must be more deep-seated, and involve either a displacement of, or a change of volume in, the material underlying the outer crust.

This is no occasion to enter into detail, and so I have merely indicated the general character of the studies which have gradually forced me to the conclusion that great earthquakes, and also to a great extent those lesser ones which are commonly classed as tectonic, do not owe their origin to the tectonics of the outer crust, but to processes and changes which take place in the material below it. What these processes may be we cannot know, with the certainty which comes from direct observation, for such knowledge as we think we have comes from inference, deduction, and, to some extent, simple assumption; but suggestions have been made which possess a considerable degree of probability. Among these, and especially apposite to present considerations, may be placed Dr. L. L. Fermor's studies of the changes in mineral aggregation which may take place in the solidification of a magma; he has suggested that the determining factor in deciding the form in which the rock finally solidifies, is the inter-relation of pressure and temperature, and has shown that the change of volume, consequent on the change from one mode to another, may amount to over 20 per cent. in extreme cases. Mr. W. H. Goodchild has also studied the subject from another point of view, and suggested that some of the changes, especially the separation of metallic sulphides, take place with great, even explosive, rapidity.

I may point out that we have, within our common everyday experience, familiar analogies to those changes which are presumed to take place in the material below the outer crust. Every time that we fire a gun, the impact of the hammer starts a change, by which the chemical elements, forming the material of the charge, pass from one mode of combination to another in which they occupy a vastly greater space, and in so doing give rise to the pressure by which the projectile, whether ball or shot, is propelled.

The familiar lecture experiments of supersaturated solutions, which remain liquid until some disturbance, or the introduction of foreign matter, causes a rapid solidification, accompanied by a change of bulk, offer another analogy; and a third group of possible changes is represented by those allotropic alterations with which we are familiar, of which the alteration of aragonite into calcite may be quoted as an example.

It is not improbable that, in the material beneath the outer crust, changes, more or less analogous to one or other of these types, are taking place, some slow and gradual, others more rapid and sudden, but all accompanied by a greater or less change of bulk, either of increase or decrease; and, if this be accepted, we find an explanation, not only of the forms and origin of earthquakes, but of many other phenomena, which are difficult of explanation on any hypothesis of contraction and compression alone. On the one hand, slow movements of elevation such as that of the northern Scandinavian region may be attributed to slow and gradual change involving the whole bulk of large masses, the lesser earthquakes may be due to more rapid changes in smaller portions, the greater to transformations involving a larger bulk of material, and possibly a more abrupt change of combination and density; while the greatest earthquakes, of first-class magnitude, result from similar changes involving a large bulk of material, the difference between the origin of small and great earthquakes being analogous to the difference in the effect of the explosion in a shot-gun, and that of the Vimy mines, or the recent havoc at Oppau.

To elaborate these considerations forms no part of my purpose; enough has been said to show that, even in our very fragmentary knowledge of what goes on within the substance of the Earth, we have means of explaining and interpreting the greater part of the facts known to us regarding the character of earthquakes. I shall, therefore, end my address by summing up the conclusions which have been put forward, as to origin and cause. These are, first, that earthquakes are not due to any slow acting process of secular duration, but to a rapid, possibly instantaneous, development of strain, a conclusion which I believe to be true of the greater part, at least, of those earthquakes usually classed as tectonic, and of all those of great magnitude; and, secondly, that the development of strain is not the result of processes which have produced the tectonic structures recognized by surface observation, but to changes and displacements in the matter which lies below the cooled and solid outer crust.

February 22nd, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

Irene Helen Lowe, M.Sc., Egremont, Manorgate Road, Kingston Hill (Surrey), and Trevor Hughes Stonehouse, Lawnswood House, Hill Grove Crescent, Kidderminster, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Description of a New Plesiosaur from the Weald Clay of Berwick (Sussex).' By Charles William Andrews, B.A., D.Sc., F.R.S., F.G.S.

2. 'The Carboniferous Rocks of the Deer-Lake District of Newfoundland.' By Thomas Landell-Mills, F.G.S., Arthur Smith Woodward, LL.D., F.R.S., Pres.L.S., F.G.S., and Albert Gilligan, D.Sc., B.Sc., F.G.S.

Specimens, microscope-slides, lantern-slides, and maps were exhibited in illustration of the above-mentioned papers.

March 8th, 1922.

Mr. R. D. Oldham, F.R.S., Vice-President,
in the Chair.

Cecil Stevenson Garnett, 25 Crompton Street, Derby; George Johnston, Keloil, Kelham, Newark (Nottinghamshire); William Russ, B.Sc., Assistant Geologist, Geological Survey of Northern Nigeria; and Cecil Edgar Tilley, B.Sc., A.I.C., Emmanuel College, Cambridge, were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. A. Smith Woodward described certain photographs (natural size) of *Desmostylus* teeth from the Lower Miocene Sandstone of Southern Vancouver Island (B.C.) exhibited by Ira E. Cornwall, F.G.S.

The exhibitor wrote that these *Desmostylus* teeth are slightly different from any found in either California or Japan, as they show a well-developed cingulum. They may be from an older species than *Desmostylus hesperus*, as recent research has shown that the formation in which they were found is at least Lower

Miocene, while the formation in which *Desmostylus* remains have been found in California is Middle Miocene.

One of the teeth shown in the photographs was found in 1916 in the face of the sandstone-cliff west of Muir Creek, Sooke Bay, Southern Vancouver Island (B.C.). It was determined by the late Lawrence M. Lambe as the first right upper molar of *Desmostylus hesperus* Marsh, and is now in the British Columbia Provincial Museum at Victoria. The dimensions of this tooth are: Length = 34 mm.; width = 24 mm.; height of columns = 17 mm.; diameter of the largest column = 15 mm.; diameter of small column = 10 mm. This tooth is considerably worn. The second tooth was found in the same locality last year by the Rev. Robert Connell. Its dimensions are: Length = 47 mm.; width = 34 mm.; diameter of the largest column = 24 mm.; diameter of the smallest column = 17 mm.

The following communication was read:—

'On the Geological Importance of the Primitive Reptilian Fauna in the Upper Cretaceous of Hungary.' By Baron Francis Nopcsa, For.Corresp.G.S.

March 22nd, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

Leo Arthur Cotton, M.A., D.Sc., Assistant Professor of Geology in the University of Sydney (N.S.W.); Ivan Sidney Double, Lecturer in Geology in the University of Liverpool, 10 Trinity Road, Bootle; Edith Goodyear, B.Sc., Senior Assistant in the Geological Department of University College, London; Sidney Hall, B.Sc., 344 Brownhill Road, Catford, S.E. 6; Isabel Ellie Knaggs, 76 South Hill Park, N.W. 3; Cyrus Henry Perkins, B.A., Belcourt, St. Albans (Hertfordshire); Helen Marguerite Wood, M.Sc., 5 Hindes Road, Harrow-on-the-Hill; and Leonard Langdale Wrathall, B.Sc., A.R.S.M., 37 Gwendwr Road, West Kensington, W. 14, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President read an appeal to collectors to purchase specimens of rocks and minerals on behalf of the Cornish Miners' Relief Fund, and directed that the notice embodying the necessary particulars should be affixed to the board in the Society's hall.

The President announced that the Council had awarded the

proceeds of the Daniel-Pidgeon Fund for 1922 to HERBERT PRICE LEWIS, B.A., Geological Department, University of Sheffield. The recipient proposes to investigate the structure of Caninoid Corals occurring in the Carboniferous Limestone of North Wales at higher horizons than their reputed range.

Sir CHARLES JOHN HOLMES, Director of the National Gallery, proceeded to deliver a lecture on 'Leonardo da Vinci as a Geologist.' The Lecturer began by referring to the growth in recent years of Leonardo's reputation as a man of science. This rapid growth led recently to a reaction, and it was now not infrequently stated that Leonardo's scientific discoveries were in the nature of fortunate guess-work, and were neither proved nor accompanied by experimental research. In view of this attitude, the Lecturer felt that he could not present any statement of Leonardo's discoveries to a scientific body, such as the Geological Society, except in the form of extracts from Leonardo's own writings, which would enable them to judge for themselves whether his scientific reputation was firmly founded or not.

Reading extracts from the translations made by Mr. McCurdy and Dr. Richter, the Lecturer pointed out how Leonardo was really the first to have a large and accurate conception of the causes underlying the physical configuration of the Earth. His studies of aqueous erosion, of the formation of alluvial plains, of the process of fossilization, and of the nature of stratification, led him to a logical conviction of the immensity of geological time, and were so far in advance of the dogmatic thought of his age, that they exposed Leonardo to the charge of atheism. There can be no doubt whatever, that if he had not confided these discoveries to the almost undecipherable script of his note-books, and kept them hidden there, he would have been one of the first and most notable of the martyrs of science.

Caution thus compelled him to work in isolation, and to keep his results concealed: he had no scientific instruments, no correspondents to furnish him with observations on geological conditions elsewhere; yet his grasp of the physical history of the portions of Italy which he had personally visited, was so sound, so firmly based on experiment and research, and so entirely in accordance with modern knowledge, that he must be considered the one great geological predecessor of Lyell.

Since publication of his discoveries was impossible, Leonardo left a record of them in his paintings, as in the background of the 'Monna Lisa,' the 'Madonna & St. Anne,' and in a less degree in our own 'Madonna of the Rocks' in the National Gallery. Here we find pictures of the primeval world as he imagined it, when seas and lakes ran up to the foot of the mountains, to be slowly displaced and silted up by the detritus which the rain carried down from the summits. From this reconstruction the pictures derive that sense of action, apart from place or time, which has fascinated

generations who could not understand Leonardo's meaning as we can understand it now.

After remarks by Mr. W. Whitaker, Prof. W. W. Watts, Mr. W. Dale, and the President, a cordial vote of thanks was unanimously accorded to the Lecturer.

April 12th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, and afterwards Dr. H. H. Thomas, Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Oligocene Mosquitoes in the British Museum, with a Summary of our present Knowledge concerning Fossil Culicidæ.' By F. W. Edwards, B.A. (Communicated by the Secretary.)

2. 'On a Collection of Carboniferous Plants from Peru.' By Albert Charles Seward, Sc.D., F.R.S., Pres.G.S.

3. 'The Geological History of the Genus *Stratiotes*: an Account of the Evolutionary Changes which have occurred within the Genus during the Tertiary and Quaternary Eras.' By Miss Marjorie Elizabeth Jane Chandler. (Communicated by Mrs. E. M. Reid, B.Sc., F.L.S., F.G.S.)

Specimens were exhibited by the Geological Department of the British Museum (Natural History), and specimens and lantern-slides by the Author, in illustration of Mr. F. W. Edwards's paper.

Specimens and lantern-slides were also exhibited in illustration of Prof. A. C. Seward's and Miss M. E. J. Chandler's papers.

May 10th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

William Ernest Victor Abraham, B.Sc., Nyounghla (Upper Burma); Ernest Batchelor, c/o King, King & Co., Bombay; Edmund Ernest Stockwell Brown, Wisteria House, Wisteria Road, Lee, S.E. 13; George Tinline Button, 8 Marston Ferry Road,

Oxford; Henry Day, M.Sc., c/o Bird & Co., Research Department, P.O. Box 46, Calcutta (India); John Kane, Glenside, Wattstown, Ynishir (Glamorgan); William Rushton Parker, M.A., M.D., F.L.S., Regent Palace Hotel, W. 1; David Meredith Seares Watson, M.Sc., Jodrell Professor of Zoology & Comparative Anatomy in University College, London, 115 Greencroft Gardens, N.W. 6; and Sidney William Wooldridge, B.Sc., Demonstrator in Geology in King's College, London, 3 Bank Mansions, Herne Hill, S.E. 24, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Lower Carboniferous Succession in the Settle District and along the line of the Craven Faults.' By Prof. Edmund Johnston Garwood, Sc.D., F.R.S., V.P.G.S., and Miss Edith Goodyear, B.Sc., F.G.S.

2. 'The Miocene of Ceylon.' By Edward James Wayland, Assoc.R.C.S., F.G.S., and Arthur Morley Davies, D.Sc., Assoc. R.C.S., F.G.S.

Specimens and lantern-slides were exhibited in illustration respectively of the paper by Prof. Garwood & Miss Goodyear, and of that by Mr. Wayland & Dr. Morley Davies.

A plaster cast of a model of *Peloneustes philarcus*, modelled by the Rev. Henry Neville Hutchinson, M.A., F.G.S., & Mr. Edward Godwin, was exhibited, and it was announced that Mr. Hutchinson had presented the cast to the Society.

A photograph (presented by Mrs. A. M. Blake) of a portrait painted by Eddis, of William Blake, Pres. Geol. Soc. 1815–16, was also exhibited.

May 24th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, and afterwards Dr. G. T. Prior, F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The President then proceeded to deliver a lecture (illustrated by lantern-slides, microscope-slides, specimens of rocks, fossils, and plants) entitled 'Geological Notes on Western Greenland.' He remarked that Greenland is a 'closed' country; the trade is a monopoly of the Danish Government, and no foreigners or Danes other than Government officials are allowed to go there without special permission. On June 18th, 1921, the Lecturer left Copenhagen, accompanied by Mr. R. E. Holttum, of St. John's College,

with the primary object of collecting fossil and recent plants on Disco Island and at other localities between lat. 69° N. and 71° N. Godthaab was reached on June 28th, and Godhavn (Disco Island) on July 4th. Rather more than three weeks were passed at the Arctic Station at Godhavn with Mr. Porsild, the Director, who rendered invaluable service. The Arctic Station, which was planned and directed by Mr. Porsild, was afterwards taken over and subsidized by the Danish Government. In the course of two motor-boat excursions, a distance of over 600 miles was covered; many localities were visited on the northern and north-eastern coasts of Disco Island, on the coast of Nugsuak Peninsula, also Hare Island, Upernivik Island, Ritenbenk, Sarkak, and Jakobshavn.

Greenland is an island nearly 1700 miles long, with an average breadth of about 600 miles; approximately a hundred glaciers from the inland ice reach the sea, the largest of which (the Humboldt Glacier) ends in a cliff 60 miles broad. In the course of the lecture attention was called to the various forms of icebergs seen in Greenland waters, and to the views expressed by Mercanton on the origin of the various types. A brief account was given of some of the characteristic types of vegetation. A general account of the physical and geological features of Greenland as a whole was followed by a more detailed description of the Cretaceous and Tertiary sedimentary series of Disco Island and the Nugsuak Peninsula, and of the overlying and protecting basalts which in some places rest directly upon the old Archæan land-surface, to the exclusion of the sedimentary series. Special attention was directed to the nature of the sedimentary rocks (most of which are freshwater in origin), to the occurrence of raised beaches, to evidence of recent sinking of parts of the western coast, and to some of the more striking examples of dykes and sills in the Cretaceous and Tertiary sedimentary series.

No attempt was made to describe the palæobotanical results; but allusion was made to some of the problems presented by the Cretaceous and Tertiary floras.

A hearty vote of thanks was unanimously accorded to the Lecturer.

June 14th, 1922.

Dr. G. T. Prior, F.R.S., Vice-President,
in the Chair.

Meurig Thomas Adams, Croft House, 53 Morfa Street, Bridgend (Glamorgan); Cecil Thomas Barber, B.Sc., School House, Cookhill, near Alcester; George Stanfield Blake, B.Sc., A.R.S.M., M.I.M.M., Imperial College of Science & Technology, S.W. 7; John Henry Blizard, M.I.C.E., Roman Road, Bemerton, Salisbury; John McClelland Henderson, Ph.D., M.I.M.M., Apartado 232, Maracaibo (Venezuela); Carl Archibald Phillips, P.O. Box 459, Calcutta (India); Marie Carmichael Stopes, D.Sc., Ph.D.,

F.L.S., Givons Grove, Leatherhead (Surrey); William Torrance, F.C.S., Grootfontein School of Agriculture, Middelburg (Cape Province); and Eustace Tanfield Vachell, Osmond House, 8 Cathedral Road, Cardiff, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Petrography of the Cretaceous and Tertiary Outliers of the West of England.' By Prof. Percy George Hamnall Boswell, O.B.E., D.Sc., D.I.C., F.G.S.

2. 'On some Rugose Corals from the Burindi Series (Lower Carboniferous) of New South Wales.' By Prof. William Noel Benson, B.A., D.Sc., F.G.S., and Stanley Smith, M.A., D.Sc., F.G.S.

Lantern-slides and microscope-slides were exhibited in illustration of Prof. Boswell's paper; and specimens of fossils were exhibited in illustration of the paper by Prof. Benson & Dr. Stanley Smith.

June 28th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, and afterwards Mr. R. D. Oldham, F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the arrears of their Annual Contributions.

The following communications were read:—

1. 'The Petrology of the Metamorphosed Rocks of the Start Area (South Devon).' By Cecil Edgar Tilley, B.Sc., A.I.C., F.G.S.

2. 'The Glaciation of the Counties of Antrim, Down, and parts of Armagh, Londonderry, Tyrone, Monaghan, and Louth in Ireland.' By Major Arthur Richard Dwerryhouse, T.D., D.Sc., M.R.I.A., F.G.S.

Lantern-slides, microscope-slides, and rock-specimens were exhibited in illustration of Mr. C. E. Tilley's paper, and lantern-slides were exhibited in illustration of Major A. R. Dwerryhouse's paper.

A giant Gastropod (?) from the sandstones in the Wadhurst Clay, Hastings, was exhibited by the Geological Department of the British Museum (Natural History).

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for 1922.

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1. *On the* Junction *of* Gault *and* Lower Greensand *near* Leighton Buzzard (Bedfordshire). By George William Lamplugh, F.R.S., F.G.S. (Read May 25th, 1921.)

Contents.

Note.—Throughout this paper, where the names of fossils are printed in ordinary (Roman) type between single quotation-marks, this implies that the name is only an approximate or 'field' determination, and should not be regarded by the palæontologist as final. Where names are printed in the usual italics, the determination is expert or authoritative, and ought therefore to be of palæontological moment.

I. Introduction.

Eighteen years ago the late J. F. Walker and myself described to the Society[1] a remarkable fossiliferous limestone occurring immediately beneath the Gault at Shenley Hill near Leighton

[1] 'On a Fossiliferous Band at the Top of the Lower Greensand near Leighton Buzzard' Q. J. G. S. vol. lix (1903) pp. 234–65 & pls. xvi–xviii.

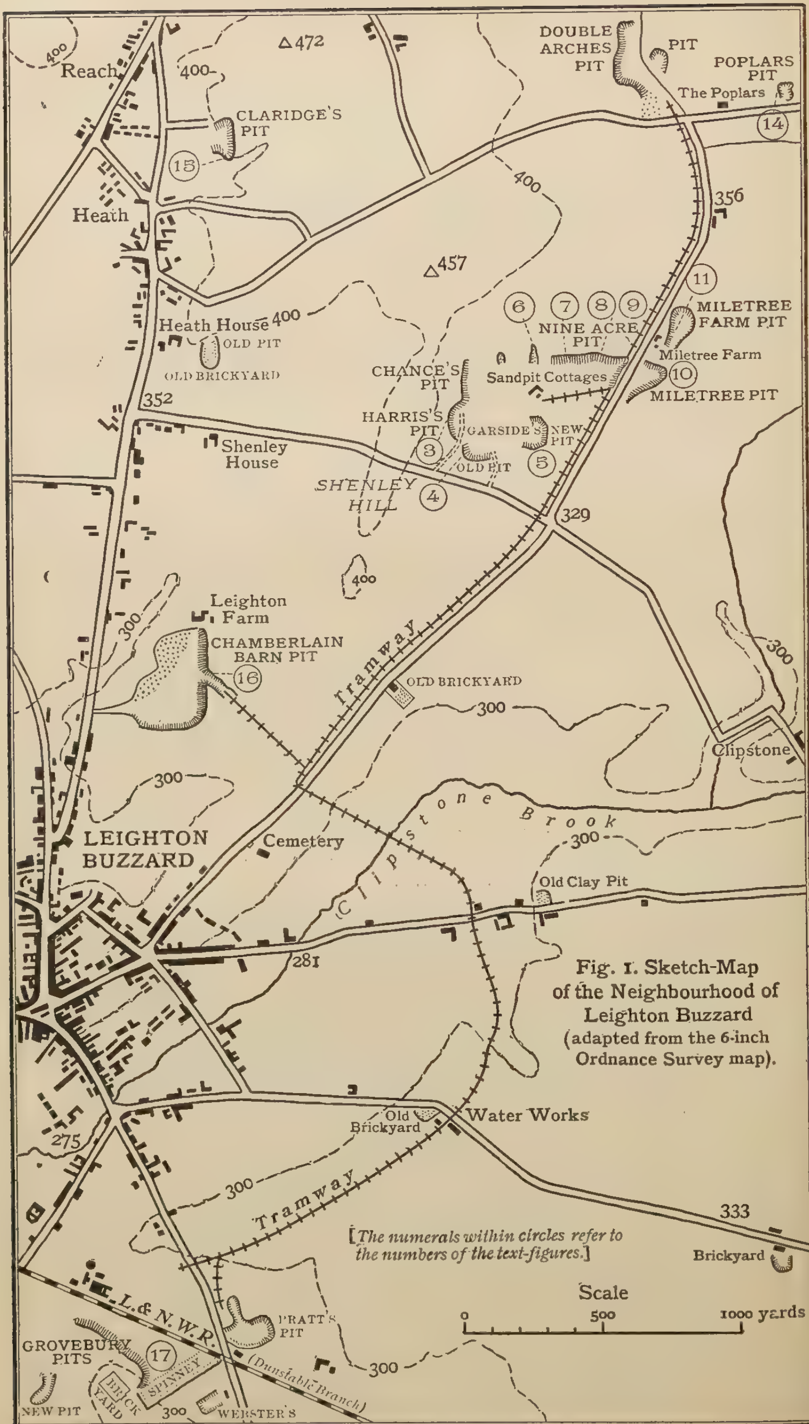


Fig. 1. Sketch-Map of the Neighbourhood of Leighton Buzzard (adapted from the 6-inch Ordnance Survey map).

[*The numerals within circles refer to the numbers of the text-figures.*]

Buzzard. The bed differed, both in its lithological characters and in its fossil contents, from any other deposit then known at this horizon in England, and the problems which it presented demanded, and have received, further investigation. Walker continued assiduously to explore the palæontology of the bed, until his work was cut short suddenly by death in 1907. Partly by personal visits to the locality, but mainly through the agency of the quarrymen, he had been able by this time very largely to increase his collection of the fossils, and had made progress in his study of the brachiopod-fauna, which was his particular interest. It was his intention ultimately to deal exhaustively with this element of the fauna, and, as a preliminary step, he had already prepared and sorted many thousands of specimens into their proper specific relationship, with provisional determinations where possible.[1] The collections thus arranged by his own hand are, however, all that remains to us of the work that he did after the publication of our joint paper.[2] Some information culled from them will be given in a later part of the present paper.

While my late colleague continued to explore the palæontology of the Shenley bed, I devoted attention, as before, more particularly to its stratigraphical aspect. Visits in successive years constantly revealed new features of interest during the continued excavation of the Shenley sand-pits, and showed also that other pits in the district were approaching the junction of the Gault with the Lower Greensand. Eventually I succeeded in obtaining evidence, long-expected, for the presence of the *Mammillatus* Bed in sections south of Leighton,[3] and afterwards in cuttings within half a mile of Shenley Hill.

The Leighton Sand trade received a great impetus as the result of the War, wherefrom the old pits have been energetically worked and several new ones opened. During last summer and autumn (1920) I was able to undertake a leisurely examination of all the sections, and I propose in this paper to combine the information thus obtained with the observations gathered at intervals since 1903, into a general review of the character of the Gault-and-Lower-Greensand junction in the district. This junction is of peculiar interest, and nowhere else in England has it been so extensively displayed in open sections.

[1] See reference to this work in 'Obituary: John Francis Walker' Geol. Mag. 1907, p. 383.

[2] By the liberality of his widow and his son, Walker's collection of brachiopoda in its entirety was presented to the British Museum (Natural History) at South Kensington, and the fossils other than brachiopoda were similarly presented to the Sedgwick Museum at Cambridge. My thanks are due to the authorities of these museums for the facilities afforded to me in examining the collections.

[3] Brief references to new features in the Shenley sections and to the discovery of the *Mammillatus* Bed south of Leighton are contained in my reports on two excursions of the Geologists' Association, 1908 & 1915, Proc. Geol. Assoc. vol. xx, p. 475 & vol. xxvi, p. 310. See also my letter on 'Gault & Lower Greensand near Leighton Buzzard' in Geol. Mag. 1920, pp. 234–37.

The attractiveness of my subject has been enhanced by the recent publication of a paper by Dr. F. L. Kitchin & Mr. J. Pringle, in which it is argued that the strata above the Lower Greensand in the Shenley Hill sections have been inverted by Glacial agency; also that there is an overlap of the Upper Gault upon the Lower Greensand in this quarter [1]; both of which suppositions can, I think, be shown to be incorrect. The discussion of these points will be dealt with separately in the concluding part of this paper, after I have described the sections of the new pits and the new features revealed in the pits previously described.

The general geological structure of the country around Leighton Buzzard was shown in the paper of 1903 by a sketch-map reduced from the Geological Survey map (Q. J. G. S. vol. lix, fig. on p. 235), and for the present purpose requires no further illustration.

As the original interest centred upon the pits under Shenley Hill, I will first record the additional information obtained from this place, and will then deal in turn with the new sections east, north-east, north-west, and south-west of Shenley. The position of the sections is marked on the outline-map (fig. 1, p. 2).

II. Description of the Sections.

The Shenley Hill pits.—Shenley Hill is composed of Gault, based on Lower Greensand, and capped and protected by the remnant of a dissected plateau of Glacial Drift, chiefly Boulder Clay. The hill rises well above the 400-foot contour, an Ordnance Trigonometrical Level of 457 feet being shown at less than 400 yards from the sand-workings. The workings themselves are on the lower slope, with an average ground-level of about 350 feet, the slope continuing south-eastwards into the broad Post-Glacial valley of the Clipstone Brook, where the 300-foot contour is reached at about half a mile south-east of the sand-pits. These are steep slopes for so ready a slipper as the Gault, and the consequences are apparent in most of the sections.

Of the three contiguous pits mentioned in the previous paper,[2] which in 1902 were being pushed westwards into the steep slope of the hill, and in which the fossiliferous limestone was sporadically exposed, the middle one only—Harris's [3]—is now in operation. Chance's on the north and Garside's on the south were abandoned about 15 years ago, and the terminal sections in both are obliterated by downwash, vegetation, and spoil; their final position is indicated on the ground-plan (fig. 2, p. 5) which, if compared with the

[1] 'On an Inverted Mass of Upper Cretaceous Strata near Leighton Buzzard, Bedfordshire; & on an Overlap of the Upper Gault in that Neighbourhood' Geol. Mag. 1920, pp. 1–15, 52–62, 100–13.

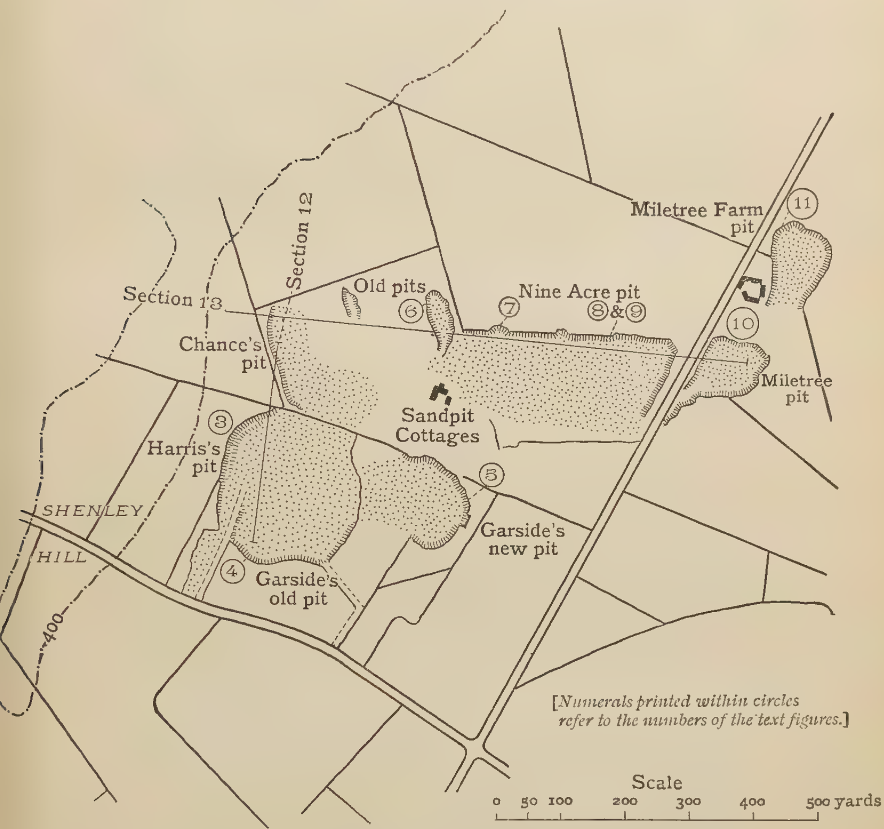
[2] For plan of the workings at that time, see fig. 2 of the paper.

[3] Through a misapprehension of the spoken name (Gregory Harris), the incorrect rendering 'Rigby Harris' was applied to this pit in the previous paper.

plan (fig. 2) in the previous paper, will give the measure of the later work.

In regard to the general succession of the deposits and the composition of the limestone-lenticles, our former descriptions have been found to hold good in all particulars, and need not be repeated. Minor changes were constantly observed in the few feet of variable

Fig. 2.—*Ground-plan of the Shenley Hill sandpits.*



beds immediately beneath the Gault, and a new feature was presented towards the western end of Garside's pit by the incoming of a wedge of greensand between the Gault and the ironstone-breccia (see figs. 4 & 12, pp. 11 & 22), but otherwise the features of the sections remained the same throughout. The limestone was seen at intervals in all three pits, always in the form of impersistent tabular lenticles of variable size. It happened often on our visits that none of the rock was visible in place, while at other times it was well

displayed. The larger masses occurred only under the low dome of unbroken iron-pan (C in fig. 3 of the previous paper) which rises from both sides towards Harris's pit, declining gently northwards and southwards, as shown in fig. 12 (p. 22). In Chance's pit on the north, the limestone became much streaked and intermingled with glauconite and grit, and was usually more or less decomposed, so that its fossils, though readily disentangled, required sizing for their preservation ; and in places the rock passed into a soft ochreous calcareous paste in which the fossils were obliterated. A large number of the specimens in the Walker Collection were obtained from this pit. Similar conditions were also observed on the south as the working in Garside's pit advanced westwards, the limestone decreasing in quantity until it was reduced to a few soft calcareous patches occurring as matrix amid the ironstone-breccia.

It is noteworthy that the cleanest and whitest 'silver sand,' for which the pits are worked, has been found under the dome, where the iron-pan floors are unbroken ; ferruginous discoloration sets in on both flanks where these bands become lenticular and brecciated, and where the firm thick tables of limestone are absent.[1]

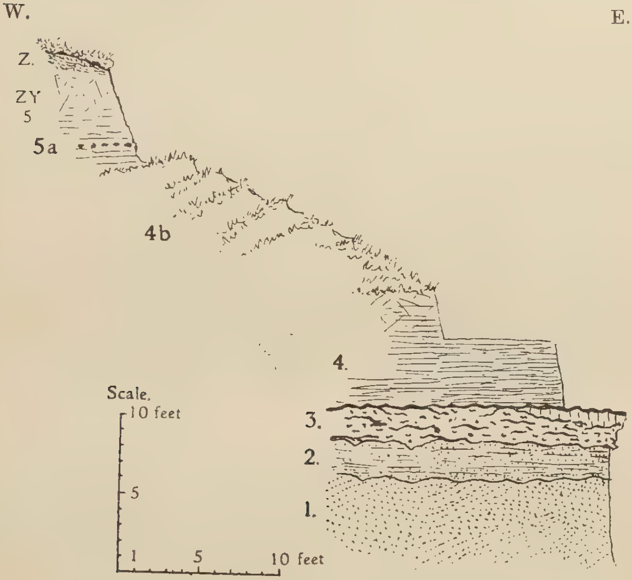
The clay-cover became steadily thicker as the workings were pushed westwards, and in this cover Harris's pit, now cutting into the steeper clay-slope, has recently disclosed some new information respecting the Gault. From its slippery character the sections in the Gault are soon spoilt, and need to be seen under favourable circumstances. Dr. Kitchin & Mr. Pringle appear to have found a clear section in this pit in October 1918, revealing about 10 feet of Gault; but they mention that this was obliterated by an extensive slip early in 1919, which, however, enabled them to examine some higher Gault, estimated to be about 18 feet above the base[2]: by careful search they obtained some fossils, hitherto unrecorded, from the sparingly fossiliferous lower portion of the Gault, together with a few others from higher levels. Last year (1920) a richly fossiliferous band was exposed near the top of the section, and enabled me to collect material which throws light on the relations of the Upper and Lower Gault in the district.

The section exposed in the northern part of Harris's pit in the autumn of 1920 is shown in the following figure (fig. 3, p. 7), which may be compared with the section farther south in the same pit in 1902, given in fig. 3 of our previous paper.

[1] Many particulars respecting the Leighton Sands from the economic standpoint, including descriptions of the workings and the methods of treatment of the material, will be found in Mem. Geol. Surv. 'Special Reports on the Mineral Resources of Great Britain : vol. vi, Refractory Materials,' &c., 2nd ed. (1920) pp. 180–83 ; and in Prof. P. G. H. Boswell's 'British Resources of Sands suitable for Glass-making, &c.' London, 1916, and 'Supplementary Memoir on British Resources of Sands & Rocks used in Glass-manufacture, &c.' London, 1917.

[2] Geol. Mag. 1920, p. 9.

Fig. 3.—*Profile section at the northern end of Harris's pit, Shenley Hill, August 1920. Surface (at breakaway), about 385 feet O.D.*



		Thickness in feet.
Z.	Brown clay-soil with flints, passing down into—	1
ZY/5.	Pale-grey marly Gault, with massive structure, disturbed and probably more or less sliding, with a few stones in the upper part, and some obscure bedding towards the bottom...............	5 to 6
5 a.	Band of phosphatic nodules of all sizes up to 6 or 8 inches in diameter, containing many fossils, in very fossiliferous pale-grey clay; some of the nodules pale grey, others black and showing scars of adherent Plicatulæ, polyzoa, etc.; both kinds generally much corroded on the upper side, and the smaller nodules frequently embedded in a regrowth of concretionary phosphate ('compound' nodules).......................	½
	Ammonites abundant but mostly fragmentary, the majority belonging to the keeled 'rostratus' group, but others akin to 'auritus,' 'splendens,' etc. 'Inoceramus sulcatus' also abundant. (See further, p. 53.)	
4 b.	Gault obscured by slips .... about	8
	['At 8 to 10 feet above the base' of the Gault Dr. Kitchin & Mr. Pringle found 'a *Hoplites* of the *tuberculatus* group' and others including 'a large involute hoplitid of flattened discoid form' apparently representing 'one of the several series whose members are commonly united under the favourite collective name *H. splendens*.' 'At this level and in the overlying part of the clay there occur large crushed examples of *Inoceramus sulcatus* Park.']	
4.	(Upper Step). Excavation in slipping ground: material mainly the pale top clay, but mixed in places towards the bottom with darker and more platy blue clay which yielded a fragment of 'Ammonites splendens'...	3
	(Lower Step). Gault in place, but with slide-planes in places, indicating movement under the slip; dark-blue (drying greyish-	

		Thickness in feet.
4. (*cont.*)	blue) platy clay, rather silty in texture, with green-mottled markings here and there: small smooth brown-coated black phosphatic nodules, widely spaced, but with linear tendency: rusty joints often coated with small selenite-crystals, giving blocky fracture, due to shrinkage and weathering with decomposition of original pyrites. Streaky green and crimson ½-inch layer in places at the base, resting on the iron-grit floor. Fossils rare, except 'Belemnites minimus' and crushed 'Inoceramus concentricus'; but there are some traces of crushed ammonites and other shells. [Dr. Kitchin & Mr. Pringle record an ammonite of the auritus-group, supposed to be ***Hoplites catillus*** (J. de C. Sowerby), and ***Nautilus deslongchampsianus*** d'Orbigny, along with a few other fossils; see *postea*, pp. 51–52]	4
3.	Iron-grit floor, 1 to 2 inches thick, with minor undulations, abraded on the knobs, and with a little coarse gritty sand preserved in some of the hollows, capping ochreous grit and ironstone-breccia with calcareous patches and ramifying veins and tables of iron-grit: as fully described in the previous paper, p. 238..	2 to 2½
2.	'Silty beds': loamy greensand, clay, etc.; as described in the previous paper (Bed F), but diminished in thickness and without the underlying lenticles of iron-grit, sandy pyritous claystone, etc. (Bed G) seen in 1902 .... about	2
1.	'Silver sands' (see former paper), worked to a depth of 18 to 20 feet	Top only shown.

All the other Shenley Hill sections have exhibited only the dark platy lower clays, usually with a 'creep' of amorphous clay above them, and this is the first section that has reached high enough to reveal the incoming of the Upper Gault fossils, 'Inoceramus sulcatus' and the keeled ammonites, although these forms have long been known to occur at another pit near Heath House, 900 yards west of the Shenley Hill pits (see p. 28).

The band of phosphatic nodules 5a is of particular interest, both from its structure and from its fossils. There can be little doubt that it is a prolongation of the nodule-bed seen by Jukes-Browne in 1884, in a brickyard-section north of Leighton Buzzard, from which he obtained numerous fossils, including eight species of ammonites (see p. 27), described as a 'mixture of Lower and Upper Gault species.'[1] The nodules are distributed rather sparsely and irregularly in a layer which could be traced horizontally for 12 or 15 yards, in the top breakaway, before being hidden by the slip. The layer was unbroken, but showed some minor undulations probably due to slipping, the pale marly clay above it being all more or less affected by 'creep.' It does not contain any extraneous coarse transported matter, differing in this respect entirely from

[1] 'The Cretaceous Rocks of Britain—vol. i: The Gault & Upper Greensand of England' Mem. Geol. Surv. 1900, p. 285. In our previous paper (*op. cit.* p. 245) I presumed that the brickyard was that, now disused, on the south-east side of the road from Leighton to Shenley Hill, 1100 yards south of the sand-pits; but I have since found that the place referred to was a working, now obliterated, near the Heath House sandpit (*postea*, p. 28).

The nodule-band in Harris's pit does not appear to have been exposed in 1919 when Dr. Kitchin & Mr. Pringle examined the section, as they state (Geol. Mag. 1920, p. 61) that 'No nodule-bed similar to that described by Jukes-Browne has been seen in any of the sections examined by us, and we are unable to test the value of his record.'

the coarse basement-beds of the Gault presently to be described. The 'compound' structure and general aspect of the nodules,[1] as well as their fossil contents, imply that they have been concentrated on the sea-floor during a rather long interval when normal sedimentation of the Gault clay was arrested, presumably by current-action. A similar phosphate-bed at about this horizon, formerly worked for 'coprolites,' is described by Jukes-Browne as occurring at several places along the outcrop of the Gault in Bedfordshire and Buckinghamshire.[2]

It is important to note that the band is also nearly on the same horizon as the nodular 'Junction Bed, VIII' of the Folkestone Gault, respecting which Price's remarks are so apposite that I will recall them. He says:—

> 'I would suggest that these lines of nodules, mixed as they are with rolled fossils, occurring so plentifully throughout the deposit, mark the floor of the sea during a period, more or less vast, when great physical changes may have altered the course of the currents, and so borne away the sediment, to be redeposited in another direction; or they may represent periods of upheaval or tranquillity, when the sea-bed was at rest. It may thus be argued that these nodule-beds, not exceeding 1 inch in thickness, are equivalent to a period of time far greater than was required for the deposition of several feet of clay.'[3]

The lowest part of the Gault has shown little or no change during the working-back of the pit, except that the impressions of crushed fossils sparingly present in it are rather less obscure than they were where the cover was thinner. Traces of the decomposition of original pyrites are very apparent, and may partly explain the poor condition of the fossils. The small brown-coated nodules, an inch or two in diameter, which occur in this part of the clay are quite different in aspect from the nodules of the higher bed just described, and have not been concentrated or corroded. A fragment of decomposed pyritous wood, 4 or 5 inches long, associated with a line of the small nodules, had however been bored by marine organisms, and was partly encrusted with small oyster-like shell-scars. The fossils of this portion of the clay will be dealt with in the discussion of the supposed overturn (pp. 51, 78).

Last autumn, no solid limestone was visible beneath the Gault in the portion of the pit illustrated. The ochreous ironstone-breccia (3) was, however, in one place very calcareous, and represented the decomposed feather-edge of a tabular mass of limestone

[1] Incidentally the nodules supply proof that the band and its associated deposits are not turned upside down, as supposed by Dr. Kitchin & Mr. Pringle. Most of the larger nodules, and many of the smaller ones, are deeply corroded on their upper surface but comparatively fresh on the under side, this being particularly conspicuous when, as is frequently the case, the nodules are casts of portions of ammonites. The under surface often presents a beautifully-smooth bright cast of the shell, whereas on the upper surface the fossil is almost or quite indistinguishable. This condition of the larger fossils is well-known in many deposits of slow accumulation, as for instance in certain parts of the Chalk and other limestones (see Proc. Geol. Assoc. vol. xviii, 1904, pp. 287–89).

[2] 'The Gault & Upper Greensand of England' Mem. Geol. Surv. *supra cit.* pp. 277–78, 280–82.

[3] 'The Gault' by F. G. Hilton Price, London, 1879, p. 9.

recently quarried away, as indicated in the figure. When I saw the section in the preceding spring the workmen were breaking through this table of limestone, which was 9 to 12 inches thick, and 10 or 12 feet long, lying everywhere in one plane immediately under the topmost layer of iron-grit. The rock was, as usual, full of fossils, and was similar in all respects to the lenticles seen and described 18 years ago.

It has occasionally happened since that time that no limestone has been met with in the pit for three or four years in succession, but every fresh patch exposed has been on exactly the same stratigraphical horizon, and has presented the same lithological peculiarities.

The sharp line between the capping iron-grit band and the bottom of the Gault in the above section marks an interval of time and of non-deposition at this spot, on which fresh light was fortunately thrown by the workings in Garside's pit immediately on the south, before they were suspended some 15 years ago. These workings will be described next.

Garside's old Shenley pit.—In 1902 the section in this pit was too near the outcrop of the base of the Gault to show a clear succession, there being only about 4 feet of disturbed and weathered clay overlying the capping of iron-grit and breccia above the 'silver sand.' But, when I revisited the locality in the following summer (1903), fresh sections had been cleared in the western part of the pit, and its north-and-south face revealed the gradual incoming of a wedge of calcareous greensand between the iron-grit floor and the Gault. The sections were practically a southward continuation of those opened up by Harris's pit. The Basement beds sloped down to 20 to 30 feet below their level in the present exposure at Harris's. The following details are from my note-book.

Section at the west side of Garside's old pit, August 15th, 1903.
Surface, about 350 feet O.D.

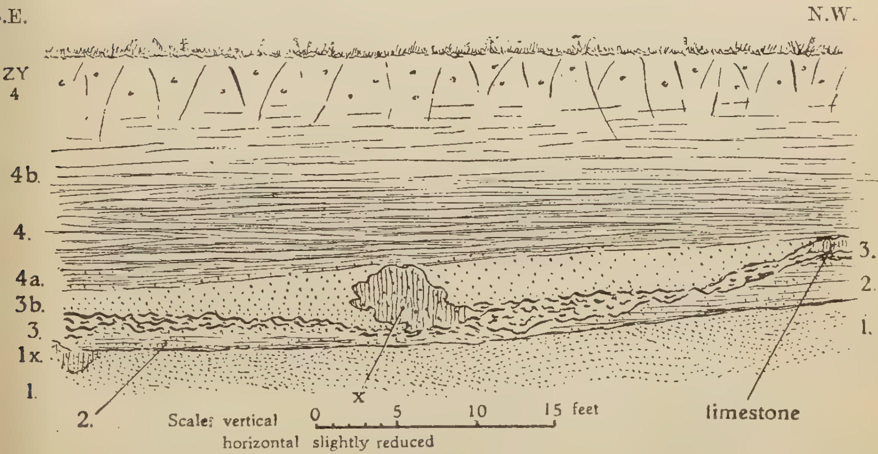
		Thickness in feet.
$\frac{ZY}{4}$.	Stiff grey-blue clay, with a few stones (probably mostly 'creep')	4
4.	Rather pale blue clay with ferruginous bands, somewhat disturbed. 'Inoceramus concentricus' plentiful in one band.	6
	Darker blue and ferruginous brownish-blue clay, yellowish and gritty in places at the base (4 a).	1
3 b.	Greensand, yellowish and rather clayey towards the top; clean, and dark sage-green below; full of worn and broken bits of shell in the lower 6 inches, but hardly any fossils in the upper part. 'Belemnites minimus,' 'Inoceramus concentricus,' small 'Ostrea,' 'Cidaris' spines, teeth of fishes, etc. (See p. 49.)	3
	The bed thins out to about 9 inches as we go 7 yards northwards; and at the next working-place, a few yards farther north, has entirely died out; but at the base of the Gault there is a dark clay-band, full of small black pebbles (lydite, etc.), about 6 inches thick, resting on—	
3.	Irregular floor of iron-grit, worn on the knobs, with breccia of ironstone, etc. in the hollows.	
2 & 1.	Lower beds as in the preceding paper, not studied in detail.	

Later in the same year (1903) the sections were examined by Mr. Walker, who sent me details which agreed with my own observations. In response to my request that he would search the greensand for fossils, he wrote:

'We [himself and his son] broke up a good many of the blocks [on the tip-heap] and also a lot of the section, but it was so damp that the fossils were softer than the matrix and they fell in pieces . . . . . . I could not see our bed [the limestone] pass into the greensand: I think it occurs underneath it; at the far end of the pit our bed is seen, but the fossils are very badly preserved: we got a few out, but the space between was covered by the fluid clay which had run down. The fossil conglomerate-bed seems to thicken towards the end of the working.'

On my next visit, in the summer of 1904, I found that some novel and highly interesting features had been revealed, as shown in the middle part of fig. 4. This figure is a combination of the three drawings made in my note-book in 1903, 1904, & 1906, and gives a somewhat shortened section across the pit from north-west to south-east.

Fig. 4.—*Combined section across Garside's old pit at Shenley Hill, from sketch-sections in 1903, 1904, & 1906, described in the text.*



Section of the south-eastern corner of Garside's old pit, August 14th, 1904. Surface, about 350 feet O.D.

		Thickness in feet.
$\frac{ZY}{4}$.	Clay with a few flints, etc., passing down into disturbed clay, passing into—	3
4b.	Rather pale-blue homogeneous Gault clay, crowded in places with 'Inoceramus concentricus.'	4
4.	Striped Gault clay, some bands dark and rather gritty (4a), others paler and some ferruginous: a few pale brown-coated nodules: fossils rare.	6

		Thickness in feet.
3 b.	Loamy calcareous greensand, with lydites and small grey irregular phosphatic nodules: fossils, chiefly towards the base and in pockets at the margin of iron-grit crag—'Belemnites minimus,' 'Inoceramus concentricus,' 'Ostrea,' Cirripedes, Serpulæ, 'Terebratula,' etc. (see p. 49).	3 to 4
X.	Protruding crag of hard purple iron-grit, worn smooth and bossy at the top and partly at the sides; with hollows and pipes both at the top and the sides filled in with fossiliferous greensand, but the summit overwrapped by Gault clay: some adherent oyster-scars in sheltered parts: ironstone-breccia against the base on the west side. Crag about 5 feet broad and 3 to 4 feet high. A smaller detached lump of similar composition, about 7 yards farther west, is probably protruding from another crag behind the present section-face.	
3.	Thin undulating pan or pans of iron-grit, associated with worn ironstone-breccia containing soft calcareous patches indicative of incipient or decomposed limestone-lenticles. The iron-grit pan fairly continuous, but sometimes duplicated, enclosing lenticles of breccia, etc.: or with breccia in hollows above or below.	1 to 3
2.	Silty beds: well-stratified loamy sand (in part glauconitic), silt, thin clay-streaks, ferruginous layers with thin tabular concretionary ironstone, etc.; at the base, tabular ironstone-lenticles up to 3 inches thick. (See section in the previous paper, fig. 3, p. 238.)	up to $2\frac{1}{2}$
1.	Orange-coloured sand passing down irregularly into silver sand: at the east side, orange-coloured and ferruginous brown sand partly converted into iron-grit (1 x) down to 6 feet, with silver sand below, to the bottom of the pit	worked to about 15

The upstanding crag of iron-grit, which was the most singular feature of the section,[1] was photographed soon afterwards by Mr. Basil Schon, F.G.S., who kindly sent me prints (exhibited). Living at that time in Ireland, I had no opportunity to visit the section again until 1906, by which time no trace of the crag was left; but I was told by the workmen that it rose higher than I saw it, before they reached the end of it. In 1906, the section was as follows:—

Section at the southern end of Garside's old pit, August 11th, 1906. Surface, about 350 feet O.D.

		Thickness in feet.
	'Top as before' [not drawn]	
4.	Gault, with well-marked bedding, dipping eastwards, brought out by ferruginous-stained bands. 'Inoceramus concentricus' very abundant, but hardly any other fossil seen. Line between Gault (4 a) and Greensand (3 b) not very well marked.	about 5 examined.
3 b.	Dark loamy greensand, thinning rapidly eastwards .... 'Belemnites,' 'Ostrea,' and other fossils as before, but nothing fresh. Sharp base.	5 to 2 and less.

[1] A brief account of the peculiarities of this section was given in my report of an 'Excursion to Leighton Buzzard' Proc. Geol. Assoc. vol. xx (1908) p. 475.

	Thickness in feet.
3. Ochreous conglomerate of partly-worn ironstone-fragments, grit-pebbles, etc.: in one place, capped by a 'table' of hard iron-grit 46 inches long and 5 inches thick; on a more or less continuous floor of generally coarse iron-grit, but passing down in one place into coarse green pebbly sand or grit. Iron-pans above the floor, mostly broken up, but with a few veins later than brecciation. No limestone visible. Sharp base.	1 to $1\frac{1}{2}$
2. Silty beds: loamy greenish sands, clays, etc., as before; on tabular ferruginous concretions	about 2
1. Silver sand.	

That the bosses of iron-grit formed crags on the sea-floor is clear from all the circumstances, and their presence is probably responsible for the preservation of the surrounding greensand, by protecting it from the full sweep of the sea-currents. The relation of the ironstone of the crags to the underlying beds is not well shown, either in my note-book section or in Mr. Schon's photographs, but may be explained by recent sections in pits on the east, presently to be described. The masses were probably indurated bosses of the main lower sands, with the breccia, etc. banked around their undercut edges, as in the Nine Acre and Miletree pits (figs. 8, 9, & 10, pp. 16, 18, & 19).

The southerly working of the pit ceased not long after my visit in 1906, for in March 1908 I found all the faces slipped and obliterated, and they have since been banked in by tip.

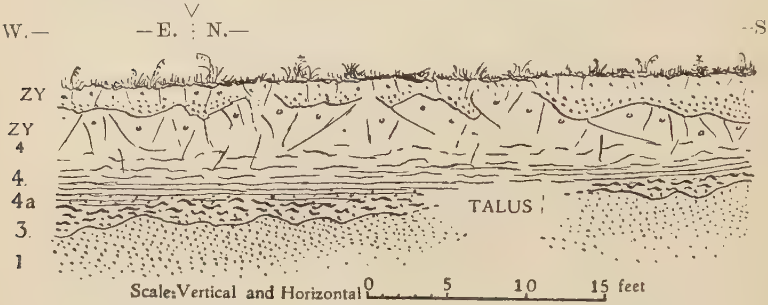
I have entered fully into the particulars of my observations at this spot, because it is held by Dr. Kitchin & Mr. Pringle that the greensand beneath the Gault (which they never saw) must have been 'Upper Greensand' brought into this position by Glacial inversion, an idea irreconcilable with the facts.

The structure of Shenley Hill in a north-and-south line, nearly parallel to its axis, is shown in the reduced section (fig. 12, p. 22), in which the sections observed in the contiguous pits are combined.

The great variability of the beds immediately below the base of the Gault in this region is exemplified to a still more striking degree in a group of practically continuous sand-workings stretching eastwards from Shenley Hill, next to be described, as well as by others on the north and west.

The positions of the easterly workings are shown on the plan (fig. 2, p. 5); most of them are still in operation, and the information now to be given embodies the evidence which they presented in the summer and autumn of last year (1920), supplemented in a few cases by observations of earlier date. They have many features in common, along with points of individual peculiarity; the following descriptions and figures of the more important portions are arranged, so far as possible, in an easterly sequence. Their relation to the section at Harris's pit, above described, is shown in the combined section (fig. 13, p. 22).

Fig. 5.—*Section at the north-eastern corner of the new (East) working of Garside's pit, Shenley Hill; 120 yards south of Sandpit Cottages. September 8th, 1920. Surface, about 340 feet O.D.*



	Thickness in feet.
ZY. Soil passing down into gravelly loam, mainly of flints with a few iron-grit fragments, quartzites, and other drift-stones and boulders; looped and contorted with underlying clay, and with slicken-planes in places := Late-Glacial gravelly wash disturbed by later 'trail' movement.	1 to 4
$\frac{ZY}{4}$. Re-arranged pale-blue Gault clay, with an occasional flint or drift-stone in the upper part: much calcareous 'race' in places: crumbly texture and massive structure with sharply-cut bright slicken-planes, probably due to 'creep': passing down into—	about 2
4 Disturbed Gault: brownish ferruginous clay, somewhat weathered, with a few small brown-coated phosphatic nodules (black inside), and much white 'race.'	$1\frac{1}{2}$ to $2\frac{1}{2}$
4a. Dark greyish-blue platy Gault; with streaks containing polished grit-grains in the lower half; and mottled streaks of dirty greensand in the lowest inch or two: in one place a lenticle of gritty greensand, half an inch thick, at the base. No fossils seen, but all the clays are more or less weathered and penetrated by tree-roots.	$\frac{3}{4}$ to 1
3. Loamy and ochreous iron-grit breccia, with some soft decomposed patches, partly calcareous, partly phosphatic; and some tabular slabs of iron-pan, measuring up to 2 feet in length and about an inch thick.	$\frac{1}{2}$ to 2
1. Orange-coloured and buff-coloured sand, rising to near the top farther south, and there passing into and capped by iron-grit.	

Section (weathered) at the east side of a small old partly-overgrown pit, 100 yards east of Chance's pit (see plan, fig. 2, p. 5), September 6th, 1920. Surface, about 350 feet O.D.

	Thickness in feet.
Z. Clay soil, with a few flints and drift-pebbles...........................	1 to 2
4. Gault, poorly exposed, weathered and crumbly, with roots of recent vegetation down to 6 feet: darkish grey-blue and platy in the lower part, with a paler band about 1 foot thick; bits of shell, but nothing identifiable found: a few small brown-coated phosphatic nodules: not much 'race': red layer at the base, on pan of iron-grit.	about 10
3. Iron-grit and ochreous breccia, slightly calcareous in places: thin tabular iron-grit 1 to 2 inches thick at the top, nearly continuous, but broken in places, with worn and polished fragments up to 4 inches in diameter below, also small polished pebbles, etc.	$\frac{1}{2}$ to $\frac{3}{4}$
1. Ferruginous brown and yellow sand with ironstone, passing at the top into dark, liver-coloured, iron-grit rock, 6 to 9 inches thick: poorly exposed to	5

Another old pit in the same field, 100 yards farther east, was being re-worked in 1903, and showed a somewhat different section from the above in its northern part, where the Basement beds (3) filled a hollow in the Sands. The section is now obscured, except at one place, where a small re-excavation, made recently for Dr. Kitchin & Mr. Pringle, shows the following succession. I understand that the so-called 'catillus' ammonite (see p. 52) was obtained from the Gault here, proving the identity of the lower part of the clay with the lower part of the clay in Harris's pit (fig. 3, p. 7), and therefore including this section in the area supposed to be inverted.

Fig. 6.—*Re-excavated section in the western bank of the old pit, 100 yards north of Sandpit Cottages, September 6th, 1920. Surface, about 350 feet O.D.*

		Thickness in feet.
	Clay-slope, slipped and overgrown; no section	about 9
ZY/4.	Palish blue-grey Gault, perhaps slipped	about 2
4.	Dark greyish-blue and mottled platy Gault, with a few small brown-coated phosphatic nodules: 'Belemnites minimus,' 'Inoceramus concentricus,' and traces of other shells very poorly preserved: passing down into—	2½
4a.	Gritty clay, with ferruginous streaks and scattered lydites, becoming more plentiful downwards: passing into—	½ to 1
3b.	Dirty loam and partly decomposed loamy greensand, sprinkled with bits of polished grit and lydite (up to ½ inch in diameter), and containing worn fragments of iron-grit (up to 8 inches) and rough gritty phosphatic nodules, externally grey, internally black (up to 6 inches in diameter, but mostly smaller).	seen to 1½
	Base obscure, but Coarse Sand (1) occurs lower in the bank.	

The obscured south-eastern part of the above-described pit is practically conterminous with the western end of the workings in the big Nine Acre pit (see plan, fig. 2, p. 5). The west-and-east face of the latter pit is rather more than 300 yards long; but the present workings are mainly at the eastern end, where the Sands rise nearly to the surface. A good section is still, however, exposed in one place near the western end (partly shown in fig. 7, p. 16) within

50 yards of that last described. In the interval of 150 yards between the section of fig. 7 and the beginning of the main easterly working, illustrated in fig. 8, the continuity and variability of the Basement beds are shown by small exposures which reveal features similar to those illustrated by the two sections here given.

When I first examined the Nine Acre pit, in a more southerly working-face, the cover of Gault had not set in; but it began to be visible, along with the iron-grit breccia, at a few spots in 1906. The sections now described are better than any previously seen. The most significant features are the very uneven surface of the lower Sands with evidence of sharp erosion around the bosses of iron-grit, and the absence of the Silty beds (2 of figs. 3, 11, 14) beneath the Basement beds of the Gault.

Fig. 7.—*Section of the western end of Nine Acre pit, Shenley, September 8th, 1920. Surface, about 350 feet O.D.*

[Same explanation as fig. 8.]

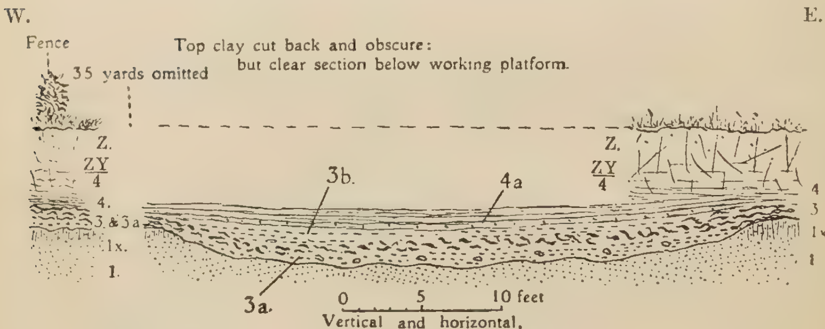
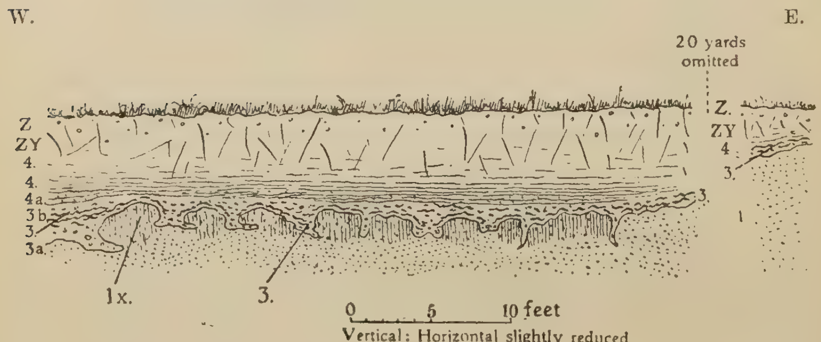


Fig. 8.—*Section at Nine Acre pit, Shenley, 150 yards east of the last (fig. 7): showing the western part of the main working face, September 10th, 1920. Surface, about 350 feet O.D.*

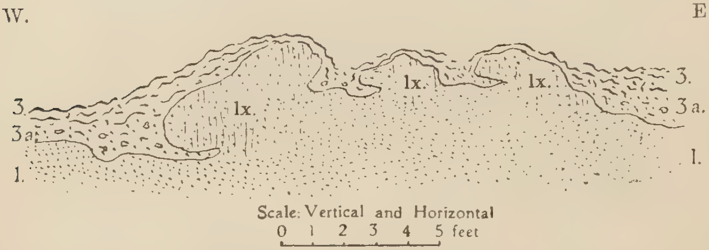


		Thickness in feet.
Z.	Clayey soil, with a few flints, etc., passing down into—	1 to 2
$\frac{ZY}{4}$.	Disturbed and weathered palish blue Gault, probably mostly 'creep,' with an occasional flint in the upper part: some 'race': penetrated by tree-roots.	2 to 4
4.	Dark greyish-blue Gault, weathered, but showing bedding in the deeper sections, with a weathered ferruginous brownish band, about 1 foot thick, in the upper part: '*Belemnites minimus*' and obscure traces of shells: some brown-coated phosphatic nodules: 'race' in places: passing down into—	0 to 6
4 a	(in hollows only). Dark gritty clay, with polished lydites, etc. (up to $\frac{1}{4}$ inch in diameter), becoming plentiful downwards: passing into—	0 to 2
3 b	(in hollows only). Gritty greensand-loam, with mottled sandy patches: contains a few rough gritty phosphatic nodules, externally grey, and occasional worn slabs of iron-grit: patches of calcareous induration: becomes mixed with ironstone-breccia downwards.	0 to 2
3.	Ironstone-breccia and undulating tabular iron-pan, the 'pan,' an inch or two thick, more or less continuous over the rises between the hollows, but broken up into short lenticles and subangular partly-worn fragments in the hollows, and set in a matrix of ochreous loam with small patches of soft decomposed phosphatic limestone and with (in fig. 7 only) occasional rough gritty phosphatic nodules.	$\frac{1}{4}$ to $\frac{3}{4}$
3 a	(in fig. 7). Dirty loamy greensand with concretionary induration, partly calcareous, partly phosphatic; resting sharply with an uneven base on—	about 1
1.	Sands, white, or only slightly lemon-stained, under the hollow in fig. 7, but elsewhere irregularly indurated at the top for a foot or two into bosses or tabular masses of hard liver-coloured iron-grit (1 x), sometimes a quartzite; the sands around and below these masses are usually stained brown, orange, or buff.	

The Gault in these sections is not thick enough to show any portion in an unweathered condition; segregations of 'race' are present in it in places throughout, and tree-roots along the line of the field-fence penetrate it, and sometimes reach into the underlying breccia-series. The upper 3 or 4 feet is massive and structureless, with an occasional flint or other stone in it, but does not present the aspect of a true boulder-clay, and is probably for the greater part 'creep'-material from the adjacent slopes. Where the Gault is shallow, it is affected by 'creep' to its base; but in the deeper sections stratification makes its appearance in the lower part, and the lowest layers are charged with smooth bright grains of grit and lydite, this gritty clay (4a) being comparatively thick within the little basins, but thinning away on their slopes. The underlying ferruginous breccia and its associated gritty greensand-loams, variable in detail but well-characterized as a whole, have partly filled the hollows of a very uneven sea-floor on which the irregular ferricrete masses at the top of the Sands have formed upstanding crags like that seen in the old Garside's pit (fig. 4, p. 11). The scouring away of the unconsolidated material from among the indurated tables has in some places left undercut gutters a foot or two deep between the crags, like those commonly seen on any

recent rocky shore or tidal reef in strata of unequal induration.[1] These features are illustrated in the following enlargement (fig. 9) of part of the preceding section.

Fig. 9.—*Enlarged section of the guttered iron-grit crags shown in the western part of fig. 8, p. 16.* [*Same explanation as for that figure.*]



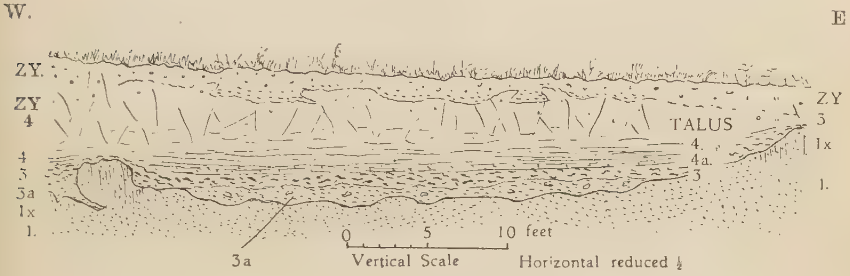
The soft calcareous patches, partly phosphatized, occurring at intervals among the ironstone-breccia in the Nine Acre sections are at the same horizon as the limestone-lenticles under Shenley Hill, and, though more decomposed, are like the lumps which occurred on the northern and southern skirts of the limestone-masses in the former workings of Chance's and Garside's pits. Traces of fossils were noticed in them in two or three cases, but in too poor a state for recognition (except in one instance as casts of brachiopods). If the pit should be pushed northwards under a thicker cover of Gault, it is probable that the section will yield better palæontological material at this horizon.

On the east, the Nine Acre workings reach the roadside near Miletree Farm, beyond which, on the other side of the road, another pit ('Miletree pit') affords practically an eastern continuation of the section, while a separate excavation ('Miletree Farm pit') is worked northwards at right angles to this. I first saw and noted these sections in 1909, and have a few particulars gleaned on later visits. Work is still in progress in both pits, but large portions of the former exposures are now obliterated. The most striking feature is the reappearance of a thick wedge of the stratified Silty beds (2) above the Silver Sands in Miletree Farm pit (fig. 11, p. 20) and their tailing out southwards at the entrance to the pit. This feature has been described and figured diagrammatically by Dr. Kitchin & Mr. Pringle (*op. cit.* p. 57). The Silver Sands are unconsolidated beneath these Silty beds, but become indurated into bosses

[1] Examples might be cited of similar features at many other geological horizons, but the closest parallel in age and structure is presented by certain of the French 'Tourtias.' The Palæozoic floor beneath the 'Tourtias' is in some places guttered and scoured in almost exactly the same way as here: see H. Parent, 'Sur l'Existence du Gault entre les Ardennes & le Bas-Boulonnais' Ann. Soc. Géol. Nord, vol. xxi (1893) figs. on pp. 207 & 212. See also pp. 56–57 of the present paper.

of iron-grit in their upper part just where the Silts thin out, under the garden of Miletree Farm, so that the adjacent Miletree pit (fig. 10) has a section showing eroded crags and hollows, like Nine Acre pit.

Fig. 10.—*Part of section at the northern end of Miletree pit, Shenley; September 13th, 1920. Surface, about 340 feet O.D.; with a gentle slope south-eastwards.*



		Thickness in feet.
ZY.	Soil, passing down into 'trail' of stony dark clay, full of flints and drift-stones, looped and pocketed among clay with few stones: passing downwards into—	3 to 4
ZY/4.	Disturbed and rearranged pale-blue Gault, mostly or wholly 'creep'; much slickensides; 'race' abundant in some patches.	2 to 3
4.	Weathered ferruginous brownish-blue Gault, with definite bedding: some 'race.'	1 to $1\frac{1}{2}$
4a.	Dark greyish-blue Gault, with rusty planes, thickly sprinkled throughout with grit and lydites (up to $\frac{1}{2}$ inch in diameter), but most abundantly towards the base: also a few brown-coated nodules (up to 2 inches in diameter), internally black and sometimes including grit grains: no fossils seen.	$\frac{1}{2}$ to $\frac{3}{4}$
3.	Iron-grit breccia, pockety, and uneven at the top and bottom, with a plentiful admixture of grit (up to 1 inch in diameter), polished fragments of ironstone, and a few pale-grey gritty phosphatic nodules; not much tabular 'iron-pan.'	$\frac{1}{2}$ to 1
3a.	Very gritty dirty sand and loam, with grit-pebbles up to $1\frac{1}{2}$ inches in diameter and a few pale gritty phosphatic nodules: in hollows and pockety; uneven base.	up to 2
1.	Coarse cross-bedded Sands indurated at the top on both sides of a hollow into irregular bosses of iron-grit (1x), quartzitic in places, up to 2 or 3 feet thick: the Sands mostly white under the hollow, but becoming stained lemon-, orange-, and coffee-coloured in the neighbourhood of the iron-grit	seen 12 to 15

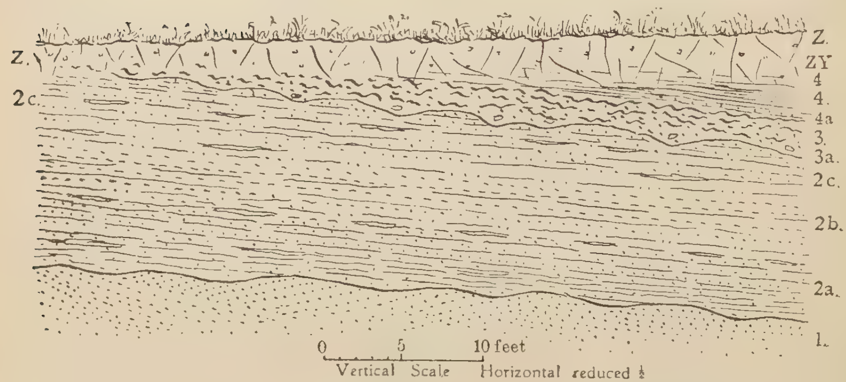
The Sands rise to the surface on both sides beyond the section, within 20 or 30 yards.

Other sections similar in the main to the above are (September, 1920) less clearly exposed on the south side of the pit; but at the entrance into it from the road, the ferruginous sands and iron-grit rise practically to the top (best seen in 1909), a continuance of the conditions visible on the opposite side of the road in Nine Acre pit. The Sands are also close to the top along the eastern side of the pit, partly owing to the downslope of the ground.

Fig. 11.—*Northern part of the section on the west side of Mile-tree Farm Pit, Shenley; September 10th & 13th, 1920, supplemented by previous observations, April 1914.*

Surface at the northern end, about 350 feet O.D., falling slightly southwards.

S.S.W. N.N.E.



	Thickness in feet.
Z. Soil and wash; at the northern end, clayey with a few stones, passing down imperceptibly into $\frac{ZY}{4}$; at the southern end, more sandy, thicker, and containing some fragments from the iron-stone-breccia.	1 to 3.
$\frac{ZY}{4}$. Disturbed and rearranged clay with an occasional flint or drift-pebble,[1] mostly 'trail' or Gault-creep; massive and slickened; in places, passing down into 4: in others, separated from 4 by a sharp slicken-plane.	0 to 3
4. Dark greyish-blue Gault, disturbed at the top; darker, and with definite bedding below: weathered and full of 'race' in places: 'Belemnites minimus,' no other identifiable fossils seen. 4a. Clay with small grit-grains, and a crimson streak in places; 2 to 3 inches thick.	0 to 5.
(The Gault thickened eastwards, in a portion of the pit now obscured.)	
3. Iron-grit breccia, ochreous, lumpy and irregular, streaked and mixed with gritty greensand-loam; soft pale calcareous concretionary patches with occasional traces of fossils; undulating and crinkled tabular 'iron-pan' at the top in places, an inch or so thick, sometimes also running among or under breccia, with smooth-worn surface under the Gault: sporadic pale gritty phosphatic nodules among the greensand-loam. 'Janira quinquecostata' was the only identifiable fossil obtained (in greensand).	$\frac{3}{4}$ to 2
3a. Mottled loamy calcareous greensand-grit with small pebbles (up to 1 inch in diameter) and occasional gritty phosphatic nodules, in hollows of the uneven eroded floor of (2).	0 to $\frac{3}{4}$
2. The Silty beds: well stratified silts and loamy sands: maximum thickness now visible as below; but all have disappeared 45 yards farther southwards, and the section is then as in Nine Acre pit.	

[1] In 1914 I found a 6-inch boulder of pink granite among the stones from the top of the section, a point worth mentioning on account of the rarity of igneous rocks in the drift of the district.

The Silty beds :—	Thickness in feet.	
2c. Banded silty greyish-white sand, darker grey carbonaceous loam and streaks of silty clay: the whole weathering buff and loamy at the outcrop: some thin tabular claystone concretions with ferruginous crust, up to 1 foot in length; also a few smaller sandy pyritous nodules, on definite bedding-planes.	5	12
2b. Streaky grey and buff loam and fine ash-coloured sand, with impersistent green streaks and streaks of coarse washed sand up to an inch or two thick; some imperfect tabular ferruginous concretions along layers, and a few fine-sandy pyritous nodules, decomposing: clayey streaks in the lower part.	3	
2a. Ashy-grey carbonaceous silts, with clay-streaks and streaky ferruginous induration forming imperfect cakes of sandy ironstone; with a 2- to 3-inch band of interlaminated wet carbonaceous greyish-brown silt and greasy-feeling grey clay at the base; resting sharply and unconformably on—	4	
Silver Sands, cross-bedded and coarse in the upper part, finer below:		seen to 18.

Dr. Kitchin & Mr. Pringle mention the occurrence of 'a few dark phosphatic nodules' about halfway down in the stratified Silty beds (2b of the above section). and on the strength of this they regard part of the beds as 'of *tardefurcata*-age' (*op. cit.* pp. 57–58). I made close search, both in this and in another section (Double Arches pit, p. 24) in which the series is well-developed, but failed to find in the Silty beds any phosphatic nodule of the kind described. The gritty phosphatic nodules in the Miletree Farm pit are confined, so far as I have seen, to the gritty greensand-loam and muddy grit associated with the ironstone-breccia (3 & 3a). The point is of consequence in the general interpretation of the sections (see p. 55). The Silts contain specks of vegetable matter in plenty, but have as yet yielded to me no identifiable fossil.

The sections of the pits above described, from Harris's pit on the west to Miletree pit on the east, are combined in the reduced section, fig. 13, p. 22, which is at right angles to the other reduced section, fig. 12, on the same page. It misses the Silty beds on the east side, and runs mainly along the belt of irregular iron-grit crags, except at the western end, where the craggy belt swings 50 to 100 yards farther south.

Sections north-east and north-west of Shenley Hill.—About half a mile north-east of the Shenley Hill pits there is another group of pits near some farm-buildings named 'The Poplars' on the 6-inch Ordnance map, where the road from Leighton joins the cross-road from Heath to Watling Street (see fig. 1, p. 2), the intervening tract being at present unbroken. One of these is an extensive re-working of an old pit, now known as 'Double Arches,' opposite the junction of the roads, and the other two are new excavations a little farther eastwards. The more easterly of these, which I shall call 'Poplars pit,' reveals the base of the Gault (fig. 14, p. 23); the western part of 'Double Arches' shows a good section in the Silty beds over the Silver Sands, but has not reached the Gault; the middle pit, at a lower level in the shallow valley which runs between the pits just named, is entirely in Sands and

Fig. 12.—*Combined section through the Shenley Hill pits, from south to north: on a reduced (natural) scale.*

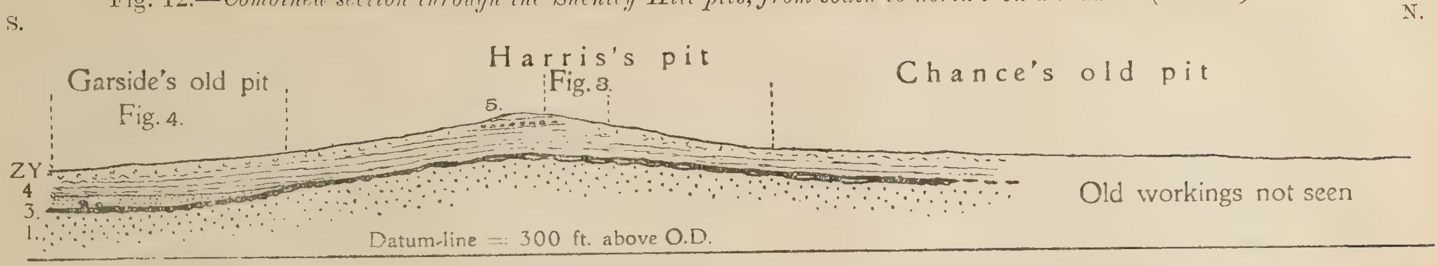
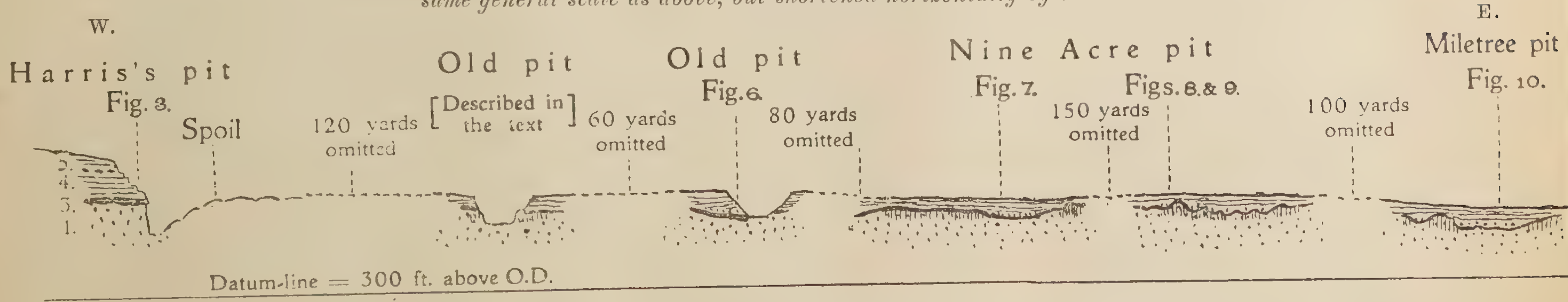


Fig. 13.—*Combined section through the pits between Shenley Hill and Miletree Farm, from west to east: same general scale as above, but shortened horizontally by omissions.*



Scale for both sections 0 10 20 30 40 50 100 yards

Horizontal and Vertical (true) 50 100 feet

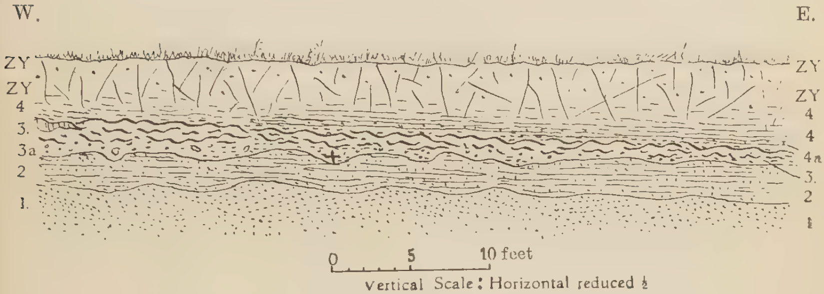
[The beds are numbered as in the preceding figures; the minor subdivisions are not shown.]

NOTE.—Harris's pit lies actually about 100 yards south of the section in fig. 13 (see ground-plan, fig. 2. p. 5); but the site is perpendicular to the western end of the section.

valley-wash, and will not here receive further notice. Poplars pit supplies the easternmost, and Double Arches pit the northernmost, of the sections dealt with in this paper.

Fig. 14.—*Section at the northern end of Poplars pit, 250 yards east-north-east of The Poplars and 1000 yards north-east of Miletree Farm; September 27th, 1920.*

Surface, on west side, 352 feet O.D., with a gentle slope south-south-eastwards.



Thickness in feet.

ZY.	Brown clayey soil, containing a few flints and drift-stones, passing down into structureless clay, probably 'creep,' with an occasional stone: passing down into—	about 3
$\frac{ZY}{4}$.	Disturbed and rearranged pale grey-blue Gault, mostly or wholly 'creep,' blocky and jointy, with crumbly structure and no clear bedding: some strong fresh slicken-planes: more or less 'race' throughout, plentiful towards the base. This material cuts out the bedded Gault (4) at the west side of the section.	$1\frac{1}{2}$ to 2
4.	Darker greyish-blue Gault, with platy structure and bedding, somewhat disturbed: the uppermost 6 inches paler, with brown rusty weathering and much 'race'; lower part, green-mottled in places: '*Belemnites minimus*' and obscure traces of other fossils.	0 to $1\frac{1}{2}$
4a.	Basal layer of gritty Gault, 2 to 3 inches thick at the eastern end, but thins on the rising slope westwards: sprinkled with small pebbles, up to half an inch in diameter: red streak at the base where resting on iron-pan.	
3.	Iron-grit breccia, ochreous; with tabular liver-coloured iron-pan 1 to $1\frac{1}{2}$ inches thick, uneven and wrinkled, fairly continuous at the top and in irregular lenticles below; associated with worn lumps and slabs of ironstone, lenticles of pebbly glauconitic loam, pale decomposed calcrete-patches with obscure traces of fossils, etc., as in Nine Acre and Miletree pits. Upper surface of iron-pan worn and abraded, with patches of pebbly glauconitic grit in the hollows; and similar material, more coarsely pebbly, (3 a) at the base of breccia in eroded hollows of underlying beds. A smooth polished cuboidal block of chert, $3 \times 3 \times 2$ inches, embedded in the glauconitic grit, was found at +, but no other pebble more than an inch in diameter was seen.	$\frac{3}{4}$ to 2
2.	Evenly-bedded streaky and mottled ashy-grey silts and silty loams, with ferruginous streaks; towards the western end, a 1- to 2-inch streak of rather dark glauconitic sand: uneven surfaces of erosion both at the top and the bottom: resting sharply on—	1 to $2\frac{1}{2}$
1.	Silver sand, mostly white and of medium grain; with some thin tabular lenticles of imperfectly-developed concretionary ironstone, passing in places into hard liver-coloured stone: worked A sump sunk to 10 feet below the floor of the pit shows similar, but rather finer, sand with a few streaks, up to half an inch thick, of fine greasy-textured grey clay, which are wrinkled and twisted like the iron-pan in (3).	10

[Postscript.—Later excavations revealed, during the summer of 1921, a tapering lenticle of fossiliferous limestone of the Shenley type, enwrapped above and below by hard iron-pan, in the upper part of the iron-grit breccia (3) at the southern corner of the western face of the pit. The lenticle, at its maximum, was $3\frac{1}{2}$ feet long and 7 inches thick, of which the inner 4 inches was pinkish and iron-stained gritty limestone. The limestone was rendered soft and crumbly by weathering, like most of the smaller patches at Shenley, and the fossils were consequently in a poor state; I obtained the casts of several small Terebratulæ and Rhynchonellids, a small Avicula and portion of an Echinoid-spine—all forms common at Shenley.]

Section at the north-western corner of Double Arches pit, 500 yards north-west of The Poplars; September 27th, 1920. Surface, about 360 feet O.D., with a strong slope eastwards at right angles to the section.

	Thickness in feet.	
Z. Soil, passing down into structureless sandy loam (downcreep and wash) with an occasional flint or other stone in the upper part.	3	
2. The Silty beds :—		5
c. Interstratified dull dark-green and brownish loams, evenly bedded as a whole, but the individual layers wispy, wavy, and inconstant: streaked with imperfect ferruginous concretions in thin tables along clayey bedding-planes, running in places into tabular clay-ironstone lenticles, best developed along the base and in the upper part of (b).	$\frac{3}{4}$ to 1	
b. Fine-grained very dark-green streaky loamy sand, traversed by faint tubular markings; a thin sprinkling of coarse polished grit in the lower part, with rare particles up to $\frac{3}{4}$ inch in diameter; a few wide-spaced hollow ironstone nodules more or less globular, in the lower part; and an impersistent band of tabular flaky ironstone at the base.	about 2	
a. Buff-coloured and rusty ferruginous loams; streaked with brown and grey unctuous silt and clay, which predominate towards the base, and throw out water: base uneven, with small and large undulations.	about 2	
1. Rather coarse Silver Sands, with rusty buff and coffee-coloured streaking and staining at the top and towards the base...............		about 20
Finer-grained sands of lower grade proved below.		

The full thickness of the Silty beds (2) has not yet been reached in the Double Arches pit, and may prove to be as great as at Miletree Farm (fig. 11, p. 20). Their quick reduction to less than 2 feet in the neighbouring Poplars Pit shows that here again, as in the Shenley group of sections, they have a wedge-like outline, which suggests that they fill hollows, partly original and partly of erosion, among the cross-bedded sand-banks of the coarse clean Silver Sands. They have, however, also been pared down, along with the coarse sands, at the close of Lower Cretaceous times. I saw no fossils, except small carbonaceous fragments, in these beds, and no phosphatic nodules. The section in the Silty beds is continued southwards, showing minor variation only, for over 100 yards; also at right angles, eastwards from the northern end, for 20 or 30 yards, until cut out by the slope of the little valley; but in other parts of the pit, the Silver Sands reach to the top.

Poplars pit provides a useful indication of the persistence of the peculiar Shenley conditions at the base of the Gault in a north-easterly direction, and Claridge's pit, next to be described, shows that they extended northwards also. The Gault at present exposed in Poplars pit is too shallow and weathered to afford palæontological data; but its lithological characters agree with those of the beds in the same position at Nine Acre (figs. 7 & 8, p. 16) and Miletree (figs. 10 & 11, pp. 19 & 20). The iron-grit breccia, with its associated gritty glauconitic stuff, is also similar in all its essentials, and the patch of fossiliferous limestone links the breccia beyond question with that of Shenley Hill. The isolated chunk of chert, which I dug out of the gritty loam infilling a hollow immediately below the breccia, is rudely cuboidal, with well-rounded angles, and possesses all over a peculiarly smooth glossy greenish surface, with perfectly fresh, dove-grey, translucent rock under it. The only other pit in which I have found extraneous stones so large as this is at Chamberlain Barn, below the 'Mammillatus beds' (p. 31). Small bits of similar chert occur among the 'lydites' of the Sands; and the rock is almost certainly the same as that found rather plentifully in the gravelly Lower Greensand at Potton and other places.[1]

West of Double Arches pit, the ground rises steadily for about 100 feet to a broad ridge which is due to a thick sheet of Glacial drift, and contracts southwards, terminating as a spur in Shenley Hill. The drift-sheet has been deeply trenched on both sides by Late-Glacial erosion, and the ground falls westwards from the ridge towards the valley of the Ouzel. On the west side most of the pits have been opened on the lower slopes, where the Sands are at the surface; but in two or three cases they have been worked back into the covering deposits, and these only will be described. The northernmost is Claridge's pit, a big working a quarter of a mile east of the high road between the villages of Heath and Reach, and nearly a mile due west of Double Arches.

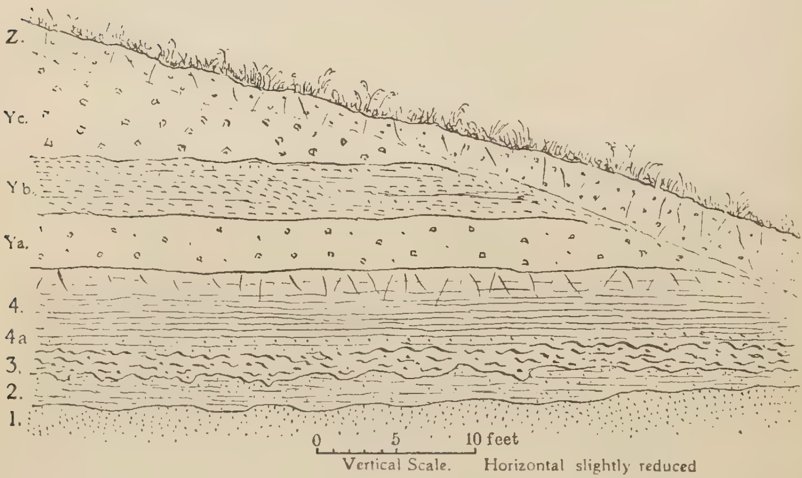
Claridge's pit (fig. 15, p. 26) has broken into a sharp spur of upland drift, and shows a thick and varied capping of Glacial deposits which come down onto the Silver Sands in the northern part of the section, but admit the feather-edge of the Gault, along with its basement-beds, in the southern part, which alone is figured. This is at present the best section exposed in the plateau-drifts of the district; but there is an old much-overgrown pit 500 yards farther north (just beyond the edge of the sketch-map, fig. 1, p. 2) which appears to have revealed a similar thickness and sequence of boulder-clays, with the addition of coarse morainic gravel at the base. In the pits on lower ground, the drift, having been eroded, is usually scanty or absent, or is of the redeposited gravelly type

[1] W. Keeping, 'On the Included Pebbles of the Upper Neocomian Sands' Geol. Mag. 1880, pp. 414–22; in which it is suggested that chert of this kind has been derived from Carboniferous strata.

and more or less influenced by 'creep' and 'trail' movements. The Glacial deposits present many features of interest, which, however, will be mentioned without discussion, as being beside our present purpose.

Fig. 15.—*Section at the southern end of the excavated platform above Claridge's pit; September 27th, 1920. Surface, at the northern end, about 410 feet O.D., rising a few feet higher northwards and falling sharply southwards.*

N. S.



		Thickness in feet.	
Z.	Clayey soil and subsoil, with flints, etc.: hill-wash................	4 to 2	
Y	c. Pale greyish Chalky Boulder Clay: massive and blue-jointed: boulders, mainly chalk and large flints, with many Jurassic rocks, including fossiliferous limestones, sandy limestones, claystones, etc., often well-glaciated.	0 to 10	
	b. Chalky gravel and sand streaked with loam: fairly well-bedded, with some cross-bedding: pebbles, mainly chalk and mostly small, averaging about 1 inch in diameter.	0 to 4	
	a. Dark sandy greenish Boulder Clay, massive and jointed: with fewer and smaller stones than in Yc., mostly flint chips and glaciated bits of chalk; occasionally a boulder: the matrix appears to include much loamy Lower Greensand material: rests with a sharp junction on Gault clay.	0 to 4	
4.	Palish grey-blue Gault clay, showing a crumbly crushed structure, but some traces of bedding: some smooth brown-coated phosphatic nodules, black internally (up to 3 inches in diameter): much 'race' in the upper part, and some throughout: passing down into—	2	5 to 6
	Darker Gault clay; brownish ferruginous weathering in the upper part; and with a gritty admixture in the lowest 2 or 3 inches (4a): structure more or less disintegrated, with a little 'race' to the bottom in places; but fairly definite bedding.	3 to 4	
	No fossils seen in the Gault.		

	Thickness in feet.
3. Iron-grit breccia, ochreous and gritty; with irregular wrinkled cakes of iron-pan, abraded at the top; worn ironstone slabs and fragments, mingled with mottled gritty glauconitic loam; and soft pale calcareous patches with small pebbles: cuts down in irregular hollows and pockets into the underlying beds.	$\frac{3}{4}$ to 2
2. The Silty beds: ashy-grey silt and loam with clay-streaks, and tabular ferruginous concretions towards the base.	1 to 3
1. Silver Sands, cross-bedded: about 30 feet seen.	

Leaving the Glacial Drift out of account, the sequence above the Silver Sands in this section is the same as that of Poplars pit, and has the same correspondence with the Miletree and Nine Acre sections. The crushed aspect of the Gault may be due to Glacial agency, but is at least as likely to be a later effect of hill-drag upon the heavily-loaded soft clays when their margin was exposed through the post-Glacial erosion of the adjacent valley. The presence of 'race,' indicative of deep weathering, is, as usual, accompanied by an absence of fossils in the Gault clay.

Heath House pit.—The next section southward requires full notice, because it figures prominently in the recent argument of Dr. Kitchin & Mr. Pringle, who refer to it as 'No. 9 Pit.' It is an obscure exposure in an old pit, formerly known as Heath House or Bushell's pit, abandoned nearly 30 years ago, in the small plantation 250 yards east of Heath House, and half a mile due south of Claridge's pit. At this place the Sands have been worked westwards beneath rising ground with a thick cover of Gault. Most of the section is hidden, and the pit partly filled, by clay-slips which now form grassy slopes; but the base of the Gault is still accessible in two or three spots on the south and east sides of the excavation, and the slipped ground itself affords some information.

This is evidently the section 'on the southern slope of . . . Heath Hill' examined by Jukes-Browne in or about the year 1884, whose account of what he saw in the pit and in an adjacent brickyard is as follows[1]:—

. . . . 'the base of the Gault is shown in a sand-pit, where 14 feet of dark-grey clay with small patches of bright-red clay at the base rest directly on yellow sand with a well-marked plane of division. This occurrence of red clay is significant in connection with the age and origin of the red marl and red chalk of Norfolk. Close by this pit is a brickyard which shows about 10 feet of bluish-grey clay with a seam of phosphatic nodules in the middle. This nodule bed appears to be a continuation of . . . [one seen at Buckland near Aylesbury] . . . for it contains a similar mixture of Lower and Upper Gault species. The following is a list of the species found by myself':—[list of 24 species, here condensed:—Ammonites:—beudanti, cristatus, interruptus, lautus, ochetonotus, rostratus, splendens, varicosus; Hamites intermedius; Belemnites minimus & var. attenuatus; Dentalium decussatum . . . . Ostrea vesicularis . . . . Inoceramus concentricus & sulcatus . . . . Nucula pectinata; Plicatula pectinoides, etc.].'

In referring to this account in our previous paper, I erroneously supposed that the brickyard was an old one still visible on the

[1] 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, p. 285.

roadside between Leighton and Shenley Hill (see fig. 1, p. 2), as I could find no other in the neighbourhood 'north of Leighton,' and no other was marked on my 6-inch Ordnance map. But recently, on looking up an earlier edition of the same map (Sheet, Beds. 28 N.E.), I notice that a 'claypit and brickyard,' of which there is now little or no trace, is shown just outside the fence enclosing the Heath House sandpit on the south, extending westwards from it. Jukes-Browne's description fits these circumstances exactly, and what I wrongly presumed to be a rather vague localization is thus made quite clear.

Some years later (1897) the pit was visited by the Geologists' Association, when already in disuse, but with better exposures than now, and a short account of it was given by A. C. G. Cameron in his report on the excursion.[1]

This was supplemented by some valuable notes by Dr. A. M. Davies in his paper on 'The Base of the Gault in Eastern England,'[2] as follows:—

'As I understand that the pit will soon be closed over, it may be well to give a full list of fossils from it. These were in part collected by my wife on the visit of the Geologists' Association, partly by myself on a later occasion. All except the belemnites are phosphatized. [List] *Hoplites interruptus*,[3] *H. tuberculatus*, *H. lautus* (?) (a worn fragment), *Schlœnbachia inflata*, *Belemnites minimus* (abundant), *Solarium*, *Dentalium*, *Inoceramas concentricus*, *I. sulcatus*; fish-scales; fish-coprolites.'

'The mixture of Upper and Lower Gault fossils is striking, but has been already noted for this district by Mr. Jukes-Browne [*ref.* "Handbook of Historical Geology, p. 412"] . . . . I should, however, add that some thickness of Gault is exposed at Heath (at least 15 feet, speaking from memory), and that owing to the large extent of slip no fossils could be obtained actually in place, so that some may have come from a higher zone than others.'

In their account of the section, Dr. Kitchin & Mr. Pringle (*op. cit.* p. 60) regard the whole of the clay as Upper Gault, and claim that the sequence here proves the inversion of the Gault of Harris's pit. But a comparison of the two sections, in the light of the information now brought together, will show that they agree in all essential particulars, except in the absence here of the Silty beds (2). Some of the nodules which I found on the upper slopes of the Heath House pit are 'compound' phosphates similar to the nodules in 5 a at Shenley and including the same fossils, and are probably from the same nodule-bed as that of the adjacent brickyard described by Jukes-Browne, as quoted above.

[1] Proc. Geol. Assoc. vol. xv (1897) p. 184.

[2] Geol. Mag. 1899, pp. 160–61.

[3] Dr. A. M. Davies informs me that these determinations of the ammonites stand in need of correction. The naming of *H. tuberculatus* has been confirmed, but the supposed *H. interruptus* is probably an *Anahoplites* of the 'splendens' group, and the *lautus?* is an indeterminable specimen.

I am indebted to Dr. Davies for the loan of the specimens; several are in the state of 'compound' phosphatic nodules, exactly like those of the nodule-bed near the top of Harris's pit, Shenley Hill (see p. 9).

The following observations, compiled from a sketch-section in my note-book, represent the present condition of the pit.

Western side of Heath House pit; October 12th, 1920.
Surface, at the highest part, 400 feet O.D.

In top breakaway:—

$\frac{ZY}{4}$. Pale-grey weathered Gault clay: little or no drift .... 2 to 4 feet seen.

On slopes:—

5. Slips of pale-grey Gault: thickness, displaced, or not seen ...... about 8 feet.
Pale hard nodules weathered out, and hard fragments of keeled ammonites: 'Ammonites rostratus,' 'Inoceramus sulcatus,' 'Dentalium,' etc.: also on the lower slope, 'Ammonites cf. splendens': probably mostly from the upper part of the section.

Section at the northern end of the pit in a trench cut for the Geological Survey; March 30th, 1920.

All the beds may be slightly slipped here.

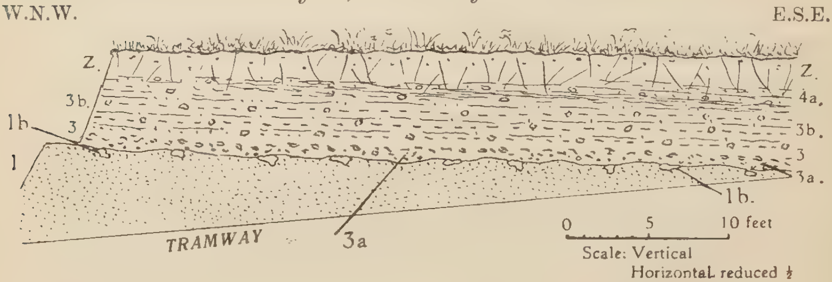
Clay, with 'Inoceramus sulcatus' (absent in beds below).
4. Darkish blue Gault, with 'Inoceramus concentricus' and allies: crushed imperfect ammonites: 'Belemnites minimus': ...... seen 4 to 5 feet.

Exposed in a steep bank above a low crag of ironstone and ferruginous Sand at the southern end of the pit.

4. Dark greyish weathered Gault, with a few small smooth brown-coated nodules: traces of pyrites: some 'race': may be slightly displaced by slip.. 2 to 3 feet seen.
3. Iron-grit breccia, poorly exposed; ochreous; with tabular pan 1 to 2 inches thick and worn iron-grit fragments .... about $1\frac{1}{2}$ feet.
1. Ferruginous coarse cross-bedded Sand; indurated at the top into massive iron-grit, forming a flat-topped crag .... seen 5 to 6 feet.

Chamberlain Barn pit.—Rather over half a mile south of the last-mentioned pit, an instructive section has been lately exposed in the eastward extension of Chamberlain Barn pit, a big working on the northern outskirts of Leighton Buzzard, which has been gradually pushed back towards the western foot of Shenley Hill, and is now in places within 1000 yards of the nearest Shenley pit (see fig. 1, p. 2). All the western part of the pit was entirely in sand, but indications that the base of the Gault was not far distant on the east were observed in 1912, and the junction is now visible in the working-face for over 200 yards, while a still better section (fig. 16, p. 30) has been exposed in a cutting for a light railway leading into the pit from the eastern side. The section is of particular consequence, in proving the relation of the iron-grit breccia and the associated fossiliferous limestone of the Shenley sections with the fossiliferous beds of the zone of Ammonites mammillatus, previously recognized in certain pits south of Leighton.

Fig. 16.—*Section on the north-west side of the tramway-cutting into Chamberlain Barn pit, Leighton Buzzard; October 14th, 1920. Surface, about 315 feet O.D.*



		Thickness in feet.
Z. Soil, rather sandy, with a few flints, drift-pebbles, and weathered gritty nodules..		about 1
4a. Weathered brownish clay, with grit and cracked phosphatic nodules: some 'race,' but not abundant; no bedding in the upper part; streaks of blue clay and gritty clay towards the base, with nodules, less gritty than those below.		1 to 2
3 b. (v) Gritty brown unstratified loam, with polished grit and lydites (up to 1 inch in diameter), some lumps of conglomerate, and gritty grey-coated fossiliferous phosphatic nodules, black internally..........................	6 inches	3 to 4
(iv) Bluish gritty clay, with similar nodules	4 inches	
(iii) Gritty loam, as above	3 inches	
(ii) Bluish gritty clay, as above	2 inches	
(i) Gritty loam, as above, with lumps of conglomerate and gritty phosphatic nodules, the latter less plentiful than in the top loam (v)	24 inches	
3. Rubbly iron-grit breccia; with ironstone in worn slabs, fragments, and flakes up to 15 inches long; some worn hematitic 'boxstones,' hollow inside or containing a little coarse sand; worn lumps of pebble-conglomerate; a few gritty phosphatic nodules; and rare quartzite and other pebbles (up to 4 inches in diameter.) Base uneven and pockety, with some patches of gritty loam (3 a) in hollows below the breccia.		$\frac{1}{2}$ to $\frac{3}{4}$
1. Cross-bedded Sands; with reefs of cross-bedded iron-grit and crimson-coated hematitic boxstones, some lined internally with quartz-crystals. At the top, immediately under the breccia, a band (1 b) of concretions of irregular shapes, sandy externally, but often having hard horny pale-grey or mottled pinkish phosphatic cores, as at Grovebury (p. 33); no fossils found in these, except sponge-like markings.		8+

The fossils from the phosphatic nodules in 3 b include 'Ammonites mammillatus,' 'regularis' (the most abundant), 'tardefurcatus,' the small form called 'beudanti,' and others; many brachiopods, lamellibranchs and gasteropods; a few echinoderms; some lobster-like crustaceans, etc. (p. 50).

These well-characterized fossiliferous nodules occur through all the beds exposed above the iron-grit breccia, as well as, more rarely, in the breccia itself. They are widely-spaced and never clustered, but display a slight tendency towards a linear arrangement; and

their grittiness appears to vary with the grittiness of their enveloping matrix, those in the more clayey upper layers being of smoother texture than those below. The fossils are mostly in the form of casts, and are only present in recognizable shape in a small percentage of the nodules, though few are without some indication, more or less obscure, of former organic structure. It is possible that prolonged investigation might reveal some difference in the contained fossils from different levels, but only a few nodules are available at a time; most of my specimens of 'Ammonites beudanti' were found in the upper part of 3b, and of 'Ammonites regularis' in the middle part, but the numbers obtained are too small to warrant a positive statement.

The breccia is more heterogeneous than the corresponding band in the Shenley Hill group of pits, and is less calcareous. Exclusive of those of iron-grit, it contains more large pebbles; among those which I collected are—one of veined felspathic grit (?), $3\frac{1}{2} \times 3 \times 2$ inches; two of quartzite, respectively $2\frac{1}{2} \times 1\frac{1}{2} \times 1$ inch and $1\frac{1}{2} \times 1\frac{1}{2} \times 1$ inch; and another of hard flaggy sandstone of similar dimensions. Besides these pebbles, I noticed several worn subangular lumps of hard conglomerate[1] up to 6 or 8 inches in diameter, composed of smooth pea- or bean-sized pebbles, mostly quartz, set in a dense pale-buff or pinkish calcareous or phosphatic cement, evidently derived from the breaking-up of a local cake or lenticle of winnowed Lower Greensand pebbles which had become bound in a limy paste. A few smaller lumps of the same conglomerate were also found in the clayey grits above the breccia. Some fragments of the same rock occur in the breccia at the Miletree pit (fig. 10, p. 19).

In the present (1920) working-face of the pit south of the tramway section, the rise of the Sands soon cuts out the overlying beds, leaving only a few nodules and hard fragments in the top-soil as a trace; but northwards the section continues, as in fig. 16, nearly to the end of the pit, at the fence adjacent to Leighton Farm. On reaching a shallow depression of the ground near the fence, the gritty clays are truncated by a wash of loamy drift with flints, etc., which has accumulated to a depth of 6 or 8 feet in a hollow, cut down into the Sands since Glacial times.

The Grovebury pits.—Other pits showing the fossiliferous Mammillatus beds, but without the ironstone-breccia, lie along the southern or Grovebury outskirts of Leighton Buzzard, adjacent to the Dunstable Branch of the London & North-Western Railway. These sections are a mile and a half south of Chamberlain Barn pit and 2 miles south-south-east of the Shenley Hill workings (see map, fig. 1, p. 2). Some small pits in the intervening tract, now abandoned, have shown only the Leighton Sands and gravelly

[1] At a casual glance the conglomerate looks not unlike some varieties of the 'Hertfordshire Puddingstone,' but is differentiated from it sharply by the absence of flint-pebbles and by the character of the matrix.

drift. A dismantled brickyard on the Stanbridge Road, near the Leighton Waterworks, was worked in the lower part of the Gault, and may at one time have revealed the junction, but showed no section when I examined it in 1912. The well-boring at the Waterworks, 150 yards farther east, is recorded[1] to have passed through:—Gravel, 10 feet; Blue Clay, $32\frac{1}{2}$ feet; Dead Sand, $9\frac{1}{2}$ feet; Blowing Red Sand & pebbles, $3\frac{1}{2}$ feet—continuing in the Lower Greensand to a depth of 144 feet.

The range of workings at Grovebury, under different proprietors, extends east and west for over half a mile, and usually displays in one part or another magnificent exposures of the cross-bedded Leighton Sands. Though similar in general structure and size of grain, the sands of these sections differ from the Silver Sands north of Leighton in colour and mineralogical character, not having the same high silica value, and therefore not being adapted for the purposes requiring that quality. Many of their well-rounded highly-polished grains are coffee-coloured, or rusty, or nearly black,[2] and these are often arranged in streaks which bring out the current-bedding beautifully. They are also frequently mottled with tubular 'worm-markings,' accentuated in the same way by the assortment of coloured grains; and some curious V-shaped structures in the mass are similarly outlined. The difference appears to be original, though it may possibly be due to some process of bleaching and ferric segregation in the Silver-Sand area, as suggested by Prof. P. G. H. Boswell.[3] It is noteworthy in this connexion that the development of hard iron-grit masses and iron-pan is rarely seen, except among the Silver Sands.

Owing to the low level of the Grovebury pits, the saturation-limit or water-table of the Ouzel valley is reached in all the deeper excavations. This has led to the adoption of a method of quarrying the Sands by steam-dredgers or diggers afloat on the pool formed in the floor of the pit, the sands being thus extracted to 20 feet or more below water-level.

It was mentioned in our paper of 1903 (*op. cit.* p. 239) that the junction of the Sands with the Gault had been nearly reached in the Grovebury pits; and the anticipation was realized in 1904, when I found that the Spinney pit (see map, fig. 1, p. 2), at that time the easternmost of the range—now worked out and filled with a deep water-pool, showed the following section:—

[1] 'Water Supply of Bedfordshire & Northamptonshire' Mem. Geol. Surv. 1909, p. 54.

[2] I am indebted to Sir Jethro Teall for the following note on these coloured grains:—'The glossy brown grains . . . are brown throughout, and when boiled in hydrochloric acid become nearly white. They are not reduced in size, and after treatment appear to consist of chalcedonic silica. The solution contains much ferric oxide' (*in litt.*, August 14th, 1920).

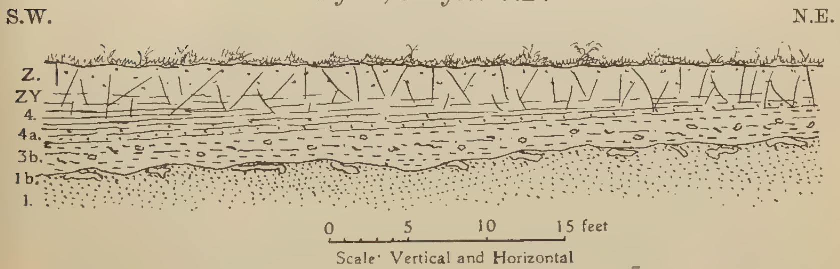
[3] 'On British Resources of Sands suitable for Glass-making, &c.' London, 1916, p. 66.

Section at the south-western corner of Spinney pit, Grovebury; August 13th, 1904. Surface, 300 feet O.D.

		Thickness in feet.
Z.	Top soil, clayey, with flint and quartzite-pebbles, merging down into—	1
ZY./4	Disturbed and rearranged Gault clay, with an occasional pebble.	about 2
4.	Stiff blue Gault, somewhat disturbed, with a few pale-coated phosphatic nodules, dark internally, mostly of tubular shape; passing down into—	about 3
3b.	Rusty and greenish glauconitic loam streaked with sandy and clayey layers; sprinkled with polished quartz-grains, lydites, and hard flaky bits of ironstone, abundantly towards the base; scattered phosphatic nodules, rather plentiful, becoming a fairly continuous band in the lower part, and there very gritty and lydite-shot; also, near the base, an occasional iron-crusted boxstone with the outside polished and worn. One of the phosphatic nodules, close to the base, held an imperfect cast of a large smooth sharp-keeled discoid ammonite; another, traces of a crustacean.	about 3
? 3a or 1b.	Rusty coarse sand, with large calcareous concretions, a few bits of ironstone, and traces of ferruginous boxstones; forms the top of the Sands, but lies parallel to the beds above, and across the current-bedding below.	$\frac{1}{2}$ to 1
1.	Coarse sharp Sand, rich coffee-coloured at the top, but grey below, with dark chocolate-coloured streaks bringing out magnificent cross-bedding and other structures.	

Similar sections were seen in 1906 and 1908 in the more easterly working of the pit; but the cover of Gault was then thinner, and no new features were observed. A year or two later the gritty phosphatic nodules began to show in fair numbers, in the detrital top-soil of the next pit on the west ('Railway' or 'Firbank's'), along a straight working-face of nearly 200 yards; and by 1912 this section showed a foot or two of weathered gritty clay containing nodules of the same kind, beneath the soil. By repeated search I collected from the nodules a fair number of fossils in the form of casts; but they were fewer here than in the sections exposed later in Pratt's pit (p. 35) and Chamberlain Barn pit (p. 30). The working-face has since been cut back for another 50 yards or so, and showed in 1920 the subjoined section (fig. 17) in a bay at the south-eastern end, where the Gault is thickest.

Fig. 17.—*Section of the south-eastern corner of 'Railway' pit adjacent to Grovebury Brickworks (adjoining the north-western corner of old Spinney pit); September 29th, 1920. Surface, 300 feet O.D.*



		Thickness in feet.
Z.	Dark clayey soil with flints, etc., passing down into—	1 to 2
ZY/4	Weathered and rearranged palish-grey Gault clay, mostly 'creep,' with crumbly structure; penetrated by roots.	1 to 3
4. 4 a.	Dark Gault, somewhat disturbed, with rusty weathering; definite bedding in the lower part: small grit-grains and pale-coated phosphatic nodules mostly of tubular shape, both becoming larger and more abundant downwards: passing down into—	about 2
3 b.	Dirty, rather rusty, gritty loam streaked with very gritty dark clay in the upper part: small pebbles, up to 1 inch in diameter: gritty phosphatic nodules of irregular shapes (pale-coated, dark inside) occur all through; also an occasional worn fragment of iron-grit, and some streaks of crimson and liver-coloured concretionary iron-pan up to $\frac{1}{4}$ inch thick. The gritty nodules are sparingly fossiliferous.	about $1\frac{1}{2}$
?1b or 3a.	Discontinuous band of large calcareous concretions, sandy outside, but often having a dense phosphatic core, usually pale buff or pinkish, but occasionally nearly black: invested by a few inches of rusty (? rewashed) sand, lying across, and cutting irregular hollows in, the cross-bedded Sands.	$\frac{1}{2}$ to 1
1.	Coarse sharp Leighton Sands with cross-bedded structure, etc. as described above (p. 32)	seen about 20.

At the north-eastern end of the section figured the working-face bends at right angles, and continues north-westwards for over 100 yards, showing the same capping beds, but more weathered, and diminished in the upper part by the slope of the ground.

Grovebury Brickyard.—In the next field on the west, within a few yards of the south-western end of the last section, and divided from it only by a fence, a small brickyard has been worked intermittently in the Gault clay during the last 20 years, and has yielded some useful information as to the upward succession. Work has been resumed here recently (autumn of 1920), but the sections are at present poor. They were better, however, in 1909 and 1912, and the following particulars are based mainly on my notes of those years, and on small collections made then and subsequently.

Sections in Grovebury Brickyard; April 1912 & September 1920.
Surface, 300 to 305 feet O.D.

	Thickness in feet.
C. In a shallow pit between the sheds and the eastern fence; 1920:—	
Pale weathered greyish crumbly Gault clay on darker blue platy clay, with small smooth brown-coated phosphatic nodules; seen in trenches only.	up to 4
'Ammonites rostratus' and 'Inoceramus sulcatus' obtained on a clay-heap from this digging.	
B. In a pit, now waterfilled, south of C; 1912:—	
Band of palish blue clay containing small brown-black phosphatic nodules with fossils: 'Ammonites auritus,' 'splendens,' etc. (see list, p. 52). Dark-blue platy clay with crushed and indeterminable fossils only.	seen about 3
A. In a sump in a deeper dry pit north of C, close to the eastern fence; 1912:—	
Gault clay, slipped and obscure (including part of B)	about 10
Gritty clay, with gritty phosphatic nodules; Sand, with big sandy nodules in a band at the top	(same as in the Sandpit, fig. 17).

The total thickness of the beds above the Sands at this place, allowing for the dip, may be 17 or 18 feet. The clay-pits are practically on the crest of a low rise, the ground falling slightly to the south and east, and rather sharply to the west and north towards the Ouzel and a tributary valley. There is no higher ground near, therefore we may assume that the top clay, although weathered and disarranged, is probably not far from its original position. The presence of the keeled ammonites and of the associated sulcated Inoceramus indicates the incoming of the Upper Gault at the top of the section, and leaves a thickness for the Lower Gault of approximately the same order as at Shenley Hill (fig. 3, p. 7) and Heath House (p. 29).

Several big sand-pits are being, or have been, worked west of Grovebury, on the slopes of the Ouzel valley, and two of these are near the top of the Sands; but none has yet reached Gault in place, and the sections, therefore, will not here be particularized. They have revealed good exposures of gravelly drift and contorted 'trail,' with Boulder Clay in places,[1] directly overlying the Sands. The drifts deserve further study, and I hope to continue the investigation of them.

In the opposite or eastward direction the main Grovebury sections terminate at the high road running south-eastwards from Leighton; but I found in 1912 that new ground had been broken on the farther or east side of the road, immediately north of the railway at 'Billington Crossing.' The section, known as Pratt's pit, was similar to that of the Spinney pit (p. 33), but afforded a better opportunity for obtaining fossils from the gritty phosphatic nodules. The pit was visited in 1915 by members of the Geologists' Association under my guidance, and the first example of 'Ammonites mammillatus' to be obtained from the bed was found on this occasion. The section at the eastern end of the pit, where the Gault was thickest, was figured and described in my report of the excursion (*op. cit.* p. 311). The text of the description is reproduced below (repetition of the figure being unnecessary). This part of the pit has since been worked out and filled in, and the present workings have reached northwards beyond the feather-edge of the Gault, but under an increasing cover of gravelly drift.

Section at the eastern end of Pratt's pit, Billington Crossing, Leighton Buzzard; 1912–1915.

		Thickness in feet.
Z.	Clayey soil, with a few stones	1—2
Y.	Pockets of drift-gravel, consisting mainly of flint and quartzite-pebbles.........	0—0½
ZY. 4	Tough dark-blue unfossiliferous Gault clay, weathering brownish and with streaks of 'race' in the upper part; becoming gritty and including a few phosphatic nodules in the lower part (4a): passing down into—	2—3

[1] For some notes on one of these sections, see Proc. Geol. Assoc. vol. xxvi (1915) p. 312. The position of another is shown in the sketch-map (fig. 1, p. 2) which falls, however, short of the other sites.

	Thickness in feet.
3b. The fossiliferous bed: gritty clay with small polished pebbles (up to ½ inch in diameter), and streaked with gritty loam and rusty weathered glauconite; small nodules (up to 6 inches in diameter) of dark gritty phosphate are scattered rather plentifully through the band, although with a few ferruginous nodules and worn fragments of ironstone	2—3
Nos. 3 and 4 become thicker towards the south.	
1. Coarse current-bedded greyish sand, with many dark coffee-coloured grains in streaks; some indurated calcareous lumps (up to 1 foot in diameter) occur (1b) immediately below the sharp junction with 3b	seen to about 20

Among the ammonites which I obtained from the nodules in this section, Dr. F. L. Kitchin identified *Leymeriella regularis* (Bruguière) and *L. tardefurcata* (d'Orbigny).

A further exposure of the same beds was open for a short time recently in 'Webster's pit,' on the east side of the road, 200 yards south of the railway-crossing, on the site marked 'Brick Works' in the 6-inch Ordnance map. The section corresponded to that seen in the adjacent Spinney pit; it was partly obscured when I visited it early in 1920, and has since been all but obliterated. It was, however, seen clearly in May 1919 by Dr. Kitchin & Mr. Pringle, from whose published account (Geol. Mag. 1920, p. 52) the following details are taken:—

Section in Webster's pit,' May 1919 [*fide* Kitchin & Pringle].
Surface, 290 feet O.D.

	Feet.	inches.
(Z) 'Soil'	1	
(4) 'Greenish-grey stiff lumpy clay with a few smooth-skinned nodules. Numerous fragments of ammonites of the *interruptus*-type occur mainly in the form of casts'	abt. 4	
(4 a) { 'Brownish sandy clay with streaks of glauconite'	1 to 2	
(4 a) { 'Thin band of dark-grey clay'		2 to 3
(3 b) 'Dark-brown well-bedded sandy clay with numerous rounded quartz-grains and pebbles. Pale-coated dark gritty phosphatic nodules of irregular shape (up to 6 inches in diameter), their surfaces studded with quartz-grains, occur sporadically throughout'	abt. 4	
(1) 'Dirty brownish-white false-bedded sand with bands and masses of iron-grit in the lowest 5 feet,' etc.	seen to 9	

The authors mention the following ammonites as having been obtained by them from the nodule-bed (3 b) of the two pits, this and Pratt's:—*Desmoceras* aff. *beudanti* (Brongniart), *Douvilleiceras mammillatum* (Schlotheim), *Leymeriella regularis* (Bruguière), *L. tardefurcata* (d'Orbigny), and *Sonneratia dutempleana* (d'Orbigny).

The Grovebury sections, as a whole, differ from those north and north-east of Leighton in the absence of a definite band of ironstone-breccia and pan, and in the fuller development of the gritty beds with phosphatic nodules at the base of the Gault. The Chamberlain Barn section (fig. 16, p. 30), with its thin and diffused breccia, affords the intermediate link; and the presence of a few worn fragments of iron-grit, and of an occasional concretionary

iron boxstone or streak of 'pan' in the gritty beds at Grovebury marks the tailing-out of the localized conditions which produced the iron-grit and its concomitants. These conditions, as will be subsequently shown, were almost certainly the existence, in a current-swept sea, of a line of sand-banks, either awash or but slightly submerged, which were indurated in places and scoured into irregular reefs, with deeper water on the south.

Brickyards in the Upper Gault.—Before leaving the Leighton sections, I will mention two brickyards in the upper part of the Gault, on the Stanbridge road, nearly 2 miles south-east of Leighton and rather over a mile east of the Grovebury pits, as reference will be made to them in the subsequent discussion, although they are not otherwise relevant to the subject of this paper. The pits, Faukner's on the south side of the road (see map, fig. 1, p. 2), and Yirrell's on the north,[1] are in pale silty marly clay of massive structure, unlike anything seen in the sections around Leighton. Fossils are very rare, and I have found nothing except impressions of 'Hamites' and crushed indeterminable shell-fragments. The absence of 'Belemnites minimus,' so plentiful in all unweathered sections around Leighton, is particularly noteworthy. The pits are 20 to 25 feet deep, and were being worked in 1920, but the greater part of the cuttings were then slipped and obscure; they were seen more clearly in 1912.

Sections south-west of Leighton and beyond.

Little is seen of the base of the Gault in the country east and west of the big sand-pits of the Leighton district, partly because of the prevalence of Glacial drift on the east and for 6 or 8 miles on the west, and partly because of the inherent weakness of the Gault, which rarely allows natural inland exposures. In three places, however, excavated sections have been observed which prove that the conditions characterizing the base of the Gault around Leighton continue, at intervals if not unbrokenly, for 17 miles or more south-westwards. [The first of these, discovered since this paper was read, is an exposure in a small sandpit in the village of Southcott, on the western outskirts of Leighton Buzzard, about a mile distant from the centre of the town.] The second was in a brickyard at Littleworth near Wing, about 3 miles south-west of Leighton; the third, in an old brickyard and stone-pit at Long Crendon in the Thame district, 17 miles south-west of Leighton. In the two last-mentioned the Basement beds have overlapped the Lower Cretaceous Sands, and rest directly on Upper Jurassic strata.

[Southcott (Buckinghamshire).—In this village, on the Buckinghamshire side of the Ouzel valley, about a mile west of the edge of my sketch-map (fig. 1, p. 2), a small sandpit has

[1] Yirrell's Pit lies just outside the eastern limit of the map.

been worked now and again for local requirements in the bottom of a little post-Glacial valley which has here trenched the sheet of Glacial drift overspreading the upland ground of the neighbourhood. The pit is in a paddock between the water-mill and the mill-pond at the western end of the village. The following section was exposed during the summer of 1921 at the south side of the pit, in a bank held up by tree-roots; it was clear in the upper part, but obscured by talus below. This section touches the side of the little valley; a fresh digging 20 yards farther north showed a clean section, but here, being in the floor of the valley, the Basement beds had been cut nearly through and replaced by gravelly wash and 'run-of-the-hill.'

Section at the southern end of the sandpit below Southcott Mill-pond, half a mile south-west of Leighton Railway Station. Height above O.D. about 310 feet.

	Thickness in feet.
ZY. Clay soil, with a few flints and drift-pebbles, passing down into—	about 1
ZY/4. Dingy-blue Gault clay, with indications of 'creep'; contains a few finger-shaped phosphatic nodules; passing into—	about 1
3 b. Streaky gritty clayey ferruginous loam, with large and small gritty phosphatic nodules of Grovebury type in the lower part, intermingled with and streaking into—	2 to 3
3. Lenticle of soft gritty pinkish fossiliferous limestone of Shenley type, with two or three of the gritty phosphatic nodules embedded in it; becoming more pebbly and gritty towards the edge, and then breaking into concretionary lumps and streaking out into 3 b.	maximum $1\frac{1}{4}$ (at the southern end).
3 a. Ferr ginous pebbly loam, poorly exposed .... 1. Coarse ochrey Leighton Sands, with indurated lumps and 'pan'	Excavated to about 8 feet, but now obscured, except at the top. 4 to 5 feet of Sand seen in the northern part of the pit.

The limestone is soft and crumbly, as usual when not well-protected, but is unmistakably of the peculiar Shenley composition, showing also the same patchy concretionary structure and the clustering of the fossils. These were in a poor state, but rather numerous in one spot; I obtained several Terebratulæ, a Rhynchonellid, small Aviculæ, and 'Janira quinquecostata,' all of the commoner Shenley forms.

The section is important in showing the association and interlinking of this peculiar kind of fossiliferous limestone with the gritty loams containing gritty phosphatic nodules, exactly like the material of the Grovebury and Chamberlain Barn sections which has yielded the Mammillatus-fauna. I broke up the limited number of gritty nodules obtainable from the small exposure, and found traces of fossils about as frequently as in those of the big sections just mentioned; but the fragments which I succeeded in collecting are not determinable, unless one fairly good cast of a bivalve should prove to be so.]

Littleworth Brickyard (Buckinghamshire).—This place is barely 2 miles south-west of the Southcott section. The brickyard is situated 400 yards north of the fork at which the Littleworth road leaves the main road from Leighton, and is worked in the slopes of a small steep-sided valley (deeper than that at Southcott) cut by a rivulet through thick Glacial drift. The surface, at the top of the pit on the south side, is about 380 feet above O.D. The yard has been in operation intermittently for over 60 years, and has been recently reopened; but the old sections are mostly obliterated, and the present exposure (October 1920) does not reveal the base of the Gault. During the original Geological Survey of the district it was examined by A. H. Green, whose observations were incorporated and first published by A. J. Jukes-Browne in his general memoir on the Gault, from which the following passages are quoted.[1]

'The late Prof. Green saw a clear section on the southern side of the excavations about 1860, and noted the succession as follows:—

		Feet.
'Drift.	Sand and pebbly sand	14
'Gault.	Pale-blue laminated clay with whity-brown phosphatic nodules	15
	Yellow earthy concretionary limestone, with much ochre, pyrites, some carbonate of copper[2] and brown phosphatic nodules	$1\frac{1}{2}$ to 2
'Kimeridge.	Stiff bluish-black clay with large septaria	6

'When I visited the place in 1884 this section was obscured, but a cut on the north side showed Kimeridge Clay passing beneath Gault without any stone-bed, and only a thin parting of brown ferruginous matter. The Gault contained *Ammonites interruptus*, *Am. lautus*, and *Bel. minimus*. In the little stream, however, which runs through the yard I found blocks of the stone described by Prof. Green, a hard calcareous ironstone full of phosphatic nodules, and containing many small Terebratulæ, which were identified by Mr. Etheridge as *Waldheimia tamarindus*,[3] a Lower Cretaceous form which however has been found occasionally in the Gault.'

When the section was re-examined many years later by Dr. A. Morley Davies, the base of the Gault was still visible in workings south of the stream, and its variable character was again demonstrated. The following are Dr. Davies's notes on the exposure, published in his report of an excursion of the Geologists' Association in 1901[4]:—

[1] 'The Cretaceous Rocks of Britain—vol. i: The Gault & Upper Greensand of England' Mem. Geol. Surv. 1900, p. 278.

[2] Films of copper-stain occur occasionally on slabs of iron-pan in the iron-grit breccia of the pits around Leighton.

[3] Some of the brachiopods from Shenley are near to this species, and it is probable that, if the Littleworth specimens were still available for comparison, they would be found to represent one of the Shenley forms.

[4] Proc. Geol. Assoc. vol. xvii (1901) p. 140. In the same writer's account of a later excursion (1914), *ibid.* vol. xxvi (1915) p. 92, when the base of the Gault was no longer visible, the particulars of the section above the Gault are stated:—'Coarse morainic gravels, 8 feet; Chalky Boulder-Clay, $2\frac{1}{2}$ feet; Sands and finer gravels, about 10 feet; Boulder-Clay, 30 feet; Gault, 17 feet.'

'In the upper diggings there were exposed about 15 feet of Drift, chiefly gravel, but with intercalations of sand, and at one place of a boulder-clay. The materials of the gravel were chiefly flint, but Coal-Measure sandstone was also found. In the lower diggings the Gault was exposed—a light bluish clay with small brownish-white phosphatic nodules, and under this a remarkable basement bed in which black phosphatic nodules (one at least a cast of a lamellibranch) were imbedded in a bright bluish-green material, while here and there masses of red oxide of iron occurred. Immediately below this came black shaly Kimeridge Clay,[1] from which the workmen had collected fossils—chiefly reptilian bones, but including also a large clavellate *Trigonia*, and a stout Belemnite évidently Jurassic. In the Gault itself, *B. minimus* was found.'

I am indebted to Dr. Davies for the loan of specimens which he obtained from the basement-bed in 1901; one is of semi-indurated calcareous glauconitic sand, olive and dark green, streaked and mottled with ochreous material, very like the glauconitic loam associated with the iron-grit breccia and limestone at Shenley Hill; another is of glauconitic sand surrounding a worn fragment of black phosphatic stone; another, of similar sand with traces of a concretionary crust, probably once pyritous. The first specimen includes some small wisps of pinkish calcareous matter, and is doubtless the concomitant and variant of the limestone seen by A. H. Green.

During my visits to the place in the autumn of 1920 the clay-pit showed a poor exposure of 10 to 15 feet of shattery dark-blue Gault containing small brown-coated nodules (black internally), surmounted by dark greenish boulder-clay like that of Claridge's pit (p. 26), with the higher drifts recorded by Dr. A. M. Davies not well seen, except the top bouldery gravel. I was informed by the proprietor that the 'green band' at the bottom of the Gault was 10 or 12 feet below the present floor. I found 'Belemnites minimus' and 'Inoceramus concentricus' plentifully, but only some poor traces of other fossils, in the Gault.

Long Crendon (Oxfordshire).—On the steep rising ground north of Long Crendon, 2 miles north-west of Thame, an irregular outlier of Gault, about a mile long and for the greater part less than a third of a mile wide, rests on an elevated platform of Purbeck and Portland rocks in which numerous stone-pits have been worked. The Jurassic strata have been described by many observers, from the time of Fitton onwards, and reference is made to the Gault in some of their descriptive sections; but the earliest observations (not however the earliest to be published) requiring

[1] On the old 1-inch Geological Survey map, Quarter-sheet 46 S.W., the Jurassic inlier along the valley west of Wing is lettered g^{13} and coloured as Portland Limestone, but the error is corrected on the later 6-inch MS. map, Bucks. xxiv, kept in the Library of the Geological Survey, this map showing the inlier as Kimmeridge Clay, with the lettering g^{12}. Last summer (1920) I saw a good exposure of dark-blue clay, with big septarian nodules of the 'cement-stone' type, at a watering-place for cattle in the brook south of Wing Park, and obscure exposures of similar clay in the banks at several spots above and below this place.

notice for the present purpose are those of Jukes-Browne,[1] made for the Geological Survey in 1885, and recorded in his memoir on the Gault. He saw at that time the following section in 'a quarry worked for stone on the east side of the road,' which can be identified as the long-abandoned working close to the old windmill, about a quarter of a mile north of the village.

Section at Long Crendon; 1885. (A. J. Jukes-Browne.)

		Thickness in feet.
'Gault.'	'Clayey soil passing down into tough grey clay, slightly micaceous and showing layers of darker and lighter grey; impressions of *Inoceramus*'	10 to 12
'Lower Greensand.'	'Brown ferruginous sandstone with small pebbles of quartz and lydianite; in places are lumps of calcareous stone'...	1 to $1\frac{1}{2}$
	'Thin layer of laminated grey and yellow clay; laminated clays with large lenticular concretions of heavy purple ironstone'	$2\frac{1}{2}$
'Purbeck and Portland Beds, seen for'		16

The interest of this record centres upon the 'lumps of calcareous stone' in the bed below the Gault, as, under Jukes-Browne's instructions, the section was visited in the same year by the Survey fossil-collector, Mr. J. Rhodes, who obtained a few fossils from the calcareous stone, which are preserved in the Survey collections at the Jermyn Street Museum.[2] These fossils, so far as they are determinable, all belong to common forms of the Shenley Hill limestone, and the matrix in which they are preserved is identical with the common type of the Shenley Hill rock. The fossils are registered as from 'Brickyard and Stone Pit, $\frac{3}{8}$ mile N.W. of Long Crendon Church.—Lower Greensand. Ferruginous sandy clay and pebble-bed on Portland Oolite.' The rock is a reddish, dense gritty limestone, with some ferruginous matter. The specimens have received the following identifications in the Survey Register:—'*Terebratula depressa ?* Lamarck [J. R. 1656]; *Terebratula capillata* d'Archiac [J. R. 1658]; *Terebrirostra lyra* Sowerby [J. R. 1677]; *Terebratella menardi* Lamarck [J. R. 1660]; *Rhynchonella latissima* Sowerby [J. R. 1678]; *Terebratula* [J. R. 1657, 1675]; *Cucullæa* (fragment) [J. R. 1664]; *Serpula*, *Cidaris* spine, and Polyzoon [J. R. 1667, 1680].' (The numerals in square brackets are the Register Nos.)

The *Cucullæa* of this list is *Septifer lineatus* (Sowerby), the commonest lamellibranch at Shenley.

The section was re-examined some years later by Dr. A. Morley

[1] 'The Cretaceous Rocks of Britain—vol. i: The Gault & Upper Greensand of England' Mem. Geol. Surv. 1900, p. 277.

[2] I owe thanks to my friend, Mr. E. T. Newton, F.R.S., formerly in charge of the Survey collections, for having written to call my attention to these fossils in 1902, soon after my discovery of the Shenley fossiliferous limestone; but I was at the time resident in Ireland, and the matter escaped my memory until revived recently by the controversy respecting the Shenley deposit. So far as I am aware, the fossils have not been mentioned in any Survey publication, and are now recorded for the first time.

Davies, who published, in 1899, the following description of it in his excellent paper, 'Contributions to the Geology of the Thame Valley' (Proc. Geol. Assoc. vol. xvi, p. 22).

'Section at Southern Windmill, Long Crendon.'
(A. M. Davies, 1899.)

		Feet.	inches.
'Gault.'	'Clay with *Inoceramus concentricus, Belemnites minimus*, and foraminifera	8	0
'? Shotover Ironsands.'	'Sand, with pebbles of quartz and lydite, and ironstone concretions containing calcite	1	6
	'Green sandy clay	1	6
	'Ironstone		6
	'Bluish clay, black at base		6
'Purbeck.'	'Limestone with clay-veins'	4	6
	With other details, down to Portland limestone.		

In a later paper Dr. Davies mentions that in the Gault here he 'failed to find ammonites, though foraminifera were plentiful' (Geol. Mag. 1899, p. 161).

I first visited the spot myself in June 1902; but by this time the deeper part of the section had become obscure, and I saw the base of the Gault only where the cover was comparatively thin and the beds much weathered. The following details are from my sketch and section of the best exposure [1]:—

Long Crendon pit, in field north of South Windmill;
June 22nd, 1902.

	Thickness in feet.
Clay (weathered Gault): thicker on the east side of the pit, now overgrown	seen 2
Ferruginous clayey stuff, sprinkled with lydite and other pebbles (up to $\frac{3}{4}$ inch in diameter)	$\frac{1}{2}$ to 2
In another exposure 15 yards farther east, the band has thickened to 2 feet, is more sandy, and at the bottom is full of lydites in a clayey base.	
Grey and ferruginous clay, with a band, about midway, of large tabular clay-ironstone septaria with concentric coating: in the lower part a white streak occurs, with small organisms; and at the bottom a wedge of grey clay with white fragments, like the earthy Purbeck breccia at Stone	2 to $2\frac{1}{2}$
Limestone: uppermost 6 inches broken up and 'pebbly'-looking	seen to 4

Like the previous observers, I regarded the gritty 'ferruginous clayey stuff' as Lower Greensand, but was (and am still) inclined to assign the underlying grey clay with tabular clay-ironstone to the Purbeck.

This area is well outside the region of thick Glacial drift, which terminates rather abruptly in steep-featured ground north of Aylesbury, 7 or 8 miles farther east. It is very generally veneered, however, with a surface-wash of flinty gravel or loam, containing a few quartzite and other stones along with the flints.

The ferruginous breccia at the base of the Gault appears to

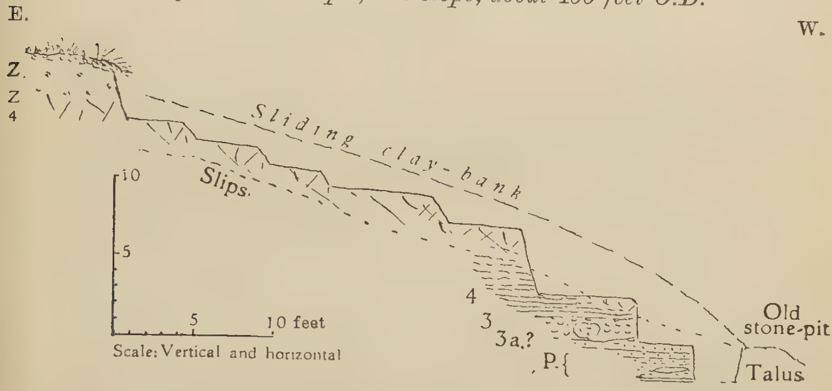
[1] It is necessary to give all available particulars regarding this section, as I believe that it is questioned whether the fossiliferous gritty limestone-lumps found by Mr. Rhodes occurred below the Gault.

have once extended over a wide area in the district, as I found traces of it in 1904 under the main outcrop of the Gault east of Thame, between Kingsey and Aston Sandford, in the then-unfinished cuttings for the Great Central Railway. At the north-western end of a cutting in Gault, I saw a poor exposure of ferruginous sandy loam full of bits of ironstone and lydites. The Gault was a dark-blue rather silty clay, with 'Belemnites minimus' and small brown-coated phosphatic nodules, seen to a depth of 8 feet.

When it became evident that the fossiliferous material obtained by the Geological Survey in 1885 from Long Crendon was identical, both lithologically and palæontologically, with the disputed Shenley rock, steps were taken by the Geological Survey to re-investigate the section, now entirely obliterated by slips and overgrowth. The requisite permission having been obtained, a trench was dug, in the autumn of 1920, in the sliding clay-slope above the old stone-pit, and was carried across the base of the Gault and its accompanying beds. From my examination of the cutting soon after it was made, I obtained the information shown in the following figure.

Fig. 18.—*Section in the trench at the east side of Long Crendon Windmill pit; September 24th, 1920.*

Surface at the top of the slope, about 400 feet O.D.



The trench, a foot and a half wide at the top, $2\frac{1}{2}$ feet at the lower part, was cut in steps, the upper part entirely in sliding Gault, but the lower part touching Gault in place, or only slightly displaced. All the beds were more or less affected by surface weathering.

		Thickness.
Z.	Brown, passing down into blue, clayey soil, with scattered flints (the largest seen, 4 inches in diameter), passing down into—	about 2 feet.
Z./4	Rather pale blue-grey mottled clay (Gault), somewhat disturbed, with some shattered small brown-coated phosphatic nodules	seen about 2 ft.

			Thickness.
4.		Sliding Gault and soil (trench 2 to $2\frac{1}{2}$ feet deep); obscure	8 to 9 feet.
	(in 2nd Step).	Blue-grey Gault, probably in place, under sliding Gault	seen about 2 ft.
	(in 1st Step).	Dark-blue Gault, probably in place (with 3 to 4 feet slipped clay above) with soft crushed decomposed traces of shells... ..	seen abt. 4 ins.
		Yellowish-grey decomposed clay, probably altered by recent weathering, with fairly sharp base on—	2 inches.
3.	(do.)	Decomposed ochreous loam, streaky and patchy, with glauconitic dabs and streaks, and soft pale calcareous patches; rather sparingly mixed with polished grit-grains and small flat worn bits of ironstone; also containing a nodular lump, 8 inches in diameter, of ferruginous pebbly material (lydites, up to 1 inch in diameter, and worn bits of ironstone), with decomposed calcareous cement, mottled with glauconite; fairly sharp base, on—	about 1 foot.
3 a? (possibly Purbeck)	(in sump).	Rusty marly sandy rock, rather flaky; like soft sandy ironstone in parts; evidently altered by weathering.	$\frac{3}{4}$ to 1 foot,
P. (supposed Purbeck).	(do.)	Ochreous weathered rather sandy clay, with a 1-inch streak of dark greenish-blue clay at the bottom.	5 inches.
	(do.)	Septarian claystone nodule, blue internally, with a crimson and liver-coloured ferruginous crust: tailing off into the ochreous clay.	
	(do.)	Rather pale buff marly clay, obscurely shown and wet	seen to 6 ins.

(Bottom of the sump filled in before my visit).

The beds below the Gault were much weathered, but it will be seen that the section is identical, so far as it goes, with those previously recorded. The conglomeratic calcareous lump in (3) may be taken as a decomposed example of the 'lumps of calcareous stone' noted by Jukes-Browne in the fresh section. Only about 8 square feet of the surface of the basement-bed was bared for examination in the recent trench. I understand that some traces of ammonites were found in the overlying Gault, but could not be preserved. It will be noticed that Jukes-Browne records only 'impressions of *Inoceramus*,' and Dr. A. M. Davies only *Inoceramus concentricus*, *Belemnites minimus*, and foraminifera; so that the Gault here, even at its best, was but sparingly fossiliferous, like the lower Gault at Shenley, and with the same kind of fauna.

III. Palæontological Notes.

Note.—In the short references within parentheses in the text of the subsequent pages (L. W.) denotes the Quarterly Journal paper of 1903 (vol. lix) by myself and Walker, and (K. P.) the Geological Magazine paper of 1920 (vol. lvii) by Dr. Kitchin & Mr. Pringle.

In attempting to deal with the palæontology of my subject, I am conscious how much has been lost to us by the death of my former fellow-worker, by whom, had he lived, the major part of the task would have been undertaken. As it is, I find myself

incapable, under the present specialized conditions of palæontological science, of doing justice to the matter; and can hope only to convey such information as may indicate the general relationship of the beds and assist the specialist in further investigation.

Additional Fossils from the Shenley Limestone.

I have already referred to the great growth of the Walker collection since our former paper was written, and to the preparatory work done on the brachiopoda by their late possessor before his death. From an examination of this collection of brachiopoda, numbering very many thousands of specimens, now preserved in the Natural History Museum at South Kensington exactly in its original state,[1] I have been able to cull some information as to the trend of Walker's later work which, even though provisional and unfinished, is likely to be of service to any future investigator. In all the lenticles of limestone which have been revealed since our former paper, the brachiopoda have been by far the most abundant element in the fauna, just as they were in those previously discovered.

Brachiopoda.—(i) In view of the controversy as to the age of the limestone, it is important to note that the absence of the common Upper Greensand forms, 'Terebratella pectita' and the typical 'Terebratula biplicata,' commented on in our former communication (p. 245), still holds good in the vastly enlarged collection.

(ii) Determinations mentioned by Walker as having been based on scanty material are now much more fully represented: as, for example, *Terebratula biplicata* Sowerby, var. *dutempleana* d'Orbigny (formerly 'a specimen,' now over 20 specimens); *Rhynchonella antidichotoma* Bav. (formerly 'one perfect,' now at least 16 specimens, with others labelled *Rh. latissima* var. *antidichotoma*); *Rhynchonella lineolata (?)* var. *mirabilis* nobis (formerly 'a remarkable specimen,' now 4 specimens labelled simply *Rh. mirabilis*). Most of the new Shenley species or varieties established by Walker are now very numerously represented in the collection.

(iii) Some additional determinations have been indicated; when written in ink, they were probably regarded as final; when in pencil, as provisional, and requiring further consideration. Among those in ink are—'Terebratula biplicata, var. ingens nobis' (many specimens:—a large form differing from the var. *gigantea* nobis of our previous paper); 'Terebratula n. sp.' (twice; two specimens, kept separate); 'Terebratula sella var.' (a single specimen, possibly only a deformed individual of some other species; the collection includes many examples of deformity); 'Terebratula obtusa Sowerby' (one specimen, labelled 'Greensand above Shenley bed. J. Webb,[2] 1904'); 'Terebratulina chrysalis Schlotheim' (6 specimens: Walker, however, must have felt some doubt about the nomenclature, as he mentioned the occurrence of the form in a letter to me, dated September 17th, 1902, but added, after the name, 'according to Schlœnbach, who refers the Essen (Tourtia) [shells] to this species'; and he did not include the name in his list published in 1903: see also his remarks on 'Terebratulina' in L. W., p. 253); 'Zeilleria

[1] Walker sorted the specimens into glass-capped boxes, and wrote his identifications with localities, etc., on the under side. The containing cabinets were presented along with the collection, which is thus kept intact.

[2] The name of one of the quarrymen from whom Walker obtained specimens.

pseudojurensis var.' (12 specimens); 'Magas orthiformis (d'Archiac) var. spiriferoides' (about 30 specimens, besides large numbers of the normal specific form and of assorted varieties; the species, according to Walker, had not previously been found in Britain, and is rare in the Tourtia; see L. W., p. 255); 'Rhynchonella leightonensis var.' (3 specimens); 'Rhynchonella cf. tripartita Pictet' (4 specimens).

The following (provisional) determinations are marked in pencil only. The species, mostly belonging to the Tourtia, are generally represented by named specimens from abroad in Walker's foreign collection, which he evidently used as the primary basis for comparison. 'Terebratula cf. rœmeri' d'Archiac, (many specimens); 'Terebratula robertoni' d'Archiac, (many specimens: see remarks on this species in L. W., p. 252); 'Zeilleria dallasiana' (2 specimens); 'Magas subconcava' (18 specimens); 'Kingena leptorhabdota' (many specimens); 'Kingena psammos' (about 30 specimens); 'Aulacothyris' (several boxes); 'Rhynchonella nuciformis var.' (about 100 specimens: see remarks on the species in L. W., p. 259); 'Rhynchonella sigma' (3 specimens: in a letter to me, dated January 30th, 1903, Walker wrote—'There is a curious new *Rhynchonella*, something like *Rh. sigma*; I shall propose the name *Rh. sigmoides* for it.' He added:—'The bulk of the Rhynchonellas belong to the *Rh. dimidiata* group; the Continental geologists lump them into this species, but I think *latissima* should be kept separate.' His later work appears to have strengthened this opinion: see (ii) above.

A large proportion of the assorted brachiopoda in the collection, particularly of the Rhynchonellids, have no names on the boxes, or a generic name only, and I know that Walker regarded some of these as probably new. His attitude in dealing with the material was expressed to me concisely as follows (*in litt.* January 16th, 1902):—'The difficulty is not to describe new species, but to prove that the old species are present in the bed.' Walker defined his conception of a species in a short paper in the Geological Magazine (pp. 15–17) in 1905, and from the point of view therein stated, he found that the specific centres of the Shenley fossils 'where the individuals are most thickly clustered and most closely resemble each other' rarely embraced the individuals which were nearest the form regarded as typical for the established species of other localities; wherefore in most cases, if an already-named species had been first described from the Shenley specimens, it would have had a somewhat different definition. The very numerous grouped but unnamed specimens in the collection will be found usually to represent Walker's ideas of the specific and varietal 'centres' calling for recognition.

The list of fossils other than brachiopoda given in L. W., p. 263, was based on my own collection, since presented (excepting a few specimens) to the Geological Survey and now preserved at the Jermyn Street Museum. The non-brachiopodous material obtained later by Walker, now in the Sedgwick Museum at Cambridge, includes a large number of forms not already in the list; but only some of these have as yet been identified, and it will not be possible to gain a comprehensive view of the fauna until the whole collection has been systematically worked through, and the fossils compared with those from analogous deposits in France and Belgium (see p. 61). The collection, however, is scanty compared with that of the brachiopods, so that instead of the species being represented by hundreds or scores of specimens, they rarely count more than units, which is to be explained partly by original sparseness, imperfect preservation, and difficulty of extraction (see L. W., p. 244), and partly, perhaps mainly, as the result of Walker having purposely selected the brachiopoda for his chief objective. As in the case of the brachiopoda, some of the forms

appear to belong to species previously unknown in this country. The following notes are intended to give a general idea of the additional fauna, without pretence to palæontological accuracy, except in the case of certain specimens at Cambridge, duly indicated, which have been submitted to expert examination.

Cephalopoda.—Although fossils of this Class have continued to be exceedingly rare, a few specimens have been obtained which are of high import. It was mentioned in the previous paper that the cast of portion of an ammonite had been found, which, though not identifiable, showed affinity to 'Ammonites milletianus.' The Walker (Cambridge) Collection now contains four specimens, all showing the same general features, three of them poorly preserved, but one, the largest, a sharp ferruginous cast, ¾ inch in diameter, in good condition and showing traces of nacreous lustre, which has been identified by Dr. Kitchin as *Leymeriella regularis* (Bruguière); and there is little doubt that the ammonite mentioned in our first description was of the same kinship. This species and its allies are the commonest forms in the gritty phosphatic nodules of the Basement beds at the Chamberlain Barn and Grovebury pits (pp. 30 & 36). Dr. Kitchin & Mr. Pringle speak of the limestone-specimens as 'derived from the *tardefurcata* bed' (K. P., p. 102), but the state of the specimens runs counter to the hypothesis of derivation, which will be shown also on other grounds to be improbable (p. 55). Their condition is quite different from that of the small round waterworn fragment of a whorl referred to in L. W., p. 244, and now in the Cambridge collection.

Another species of ammonite yielded by the limestone is represented by a single specimen which, in 1920, rewarded my search in recently-excavated material at Harris's pit. The shell, about an inch in diameter, is somewhat crushed, but otherwise fairly well-preserved, and is a smooth discoid form, without ribs, agreeing well with the form common in the Mammillatus-beds, which has been named provisionally 'Ammonites beudanti.' This form occurs, along with 'Ammonites regularis,' in fair numbers in the gritty phosphatic nodules of the Grovebury and Chamberlain Barn pits, where they are associated with scanty examples of 'Ammonites mammillatus' (pp. 30 & 36).

With regard to the belemnites, no additions have been made to the two fragmentary specimens previously recorded, of which one is now at Cambridge and the other in my own collection. The form, as stated before, is near to 'Belemnites minimus,' although rather larger than the average of that species. I notice that a German investigator, in discussing recently the Lower Cretaceous sequence of North Germany, recognizes a form intermediate between 'Belemnites aff. strombecki' and 'B. minimus' in the 'Zone of *Hoplites regularis*,' and proposes for it the name *Neohibolites minor* Stolley.[1] It is likely that the Shenley belemnite belongs to this type.

Gastropoda.—This Class is represented in the collection at Cambridge by many unnamed specimens, mostly in poor condition, but a few probably identifiable. They include examples of 'Pleurotomaria,' and probably others, in addition to the genera already recorded. I recently collected a good cast of 'Scalaria' from the limestone.

Lamellibranchiata.—Most of the species previously recorded are represented in the collection at Cambridge by a few additional specimens, along with which there are several species new to the list. Some have not yet been identified; but the following determinations have been made by Mr. H. Woods:—*Inoceramus concentricus* Parkinson (3 specimens: the largest about ¾ inch in length); *Isoarca obesa* (d'Orbigny) (5 specimens,

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[1] E. Stolley, 'Beiträge zur Kenntnis der Cephalopoden der Norddeutschen Unteren Kreide: 1. Die Belemniten des Norddeutschen Gaults (Aptien & Albien)' Geol. & Palæont. Abhandl. n.s. vol. x, pt. 3, 1911; also 'Die Gliederung der Norddeutschen Unteren Kreide' Centralbl. für Min. 1908, p. 246.

casts); *Cyprimeria* (*Cyclorisma*) resembling *rotomagensis* d'Orbigny (6 specimens); *Pecten* (*Camptonectes*) *curvatus* Geinitz (3 specimens, small); *Lima* (*Mantellum*) resembling *gaultina* Woods (2 specimens); *Lima* (*Plagiostoma*) *globosa* J. de C. Sowerby (mentioned in our previous list as 'resembling' this species; identification now confirmed on the strength of several specimens); *Pteria* (*Oxytoma*) *pectinata* (Sowerby) (many specimens: probably = 'Avicula sp. indet.' of our previous list): also (genus only) *Limatula* and *Nucula*.

Echinodermata.—The fossils of this Class in the collection at Cambridge have been recently examined by Prof. H. L. Hawkins, who has published two notes on the subject in the Geological Magazine, Feb. & Sept. 1921 (pp. 57–60 & 420–26). The following are his identifications; he says, 'Unfortunately, most of the Echinoids are very indifferently preserved, so that specific determination is often doubtful, and in some cases impossible.'

Catopygus columbarius Agassiz (2 specimens); *Nucleolites lacunosus* Goldfuss (1 specimen); *Pyrina* aff. *lævis* Agassiz (4 specimens) (all in our previous list). *Cardiaster ? latissimus* Agassiz (definitely so named in our previous list). Radioles of *Cidaris bowerbanki* Forbes.

The above are species previously recorded; the following are additions to our list:—'Pyrina' sp. nov. (? nov. gen.) (1 specimen); subsequently described and figured as *Conulopyrina anomala* Hawkins. *Pyrina* cf. *inflata* d'Orbigny (1 specimen); *P.* cf. *desmoulinsi* d'Archiac (2 specimens); *Pyrina* sp. (or spp.) (2 specimens); '*Echinospatagus*' aff. *murchisonianus* (Mantell) (1 specimen). *Cardiaster* cf. *fossarius* (Benett) (2 specimens). Internal moulds of *? Peltastes* or *? Salenia* (1 specimen); *? Pseudodiadema* or *? Diplopodia* (1 specimen); and *? Cardiaster* or *Holaster* (2 specimens).

Prof. Hawkins remarks:—'All the specimens of *Pyrina* are probably shape-variants of a single species; the forms attributed to *P. lævis* being immature.' . . . 'The outstanding feature is the relative abundance of *Pyrina*, about half of the specimens being referable to that group. This probably indicates littoral conditions' (*op. prius cit.* p. 59).

I shall have occasion to comment on this list in the concluding part of my paper (pp. 76–77).

Crustacea.—The collection at Cambridge contains several casts of the carapace recognized by Mr. H. Woods as *Cyphonotus incertus* Bell. An example of the same form, named by Mr. E. T. Newton, is among the fossils of my own collection at Jermyn Street.

Polyzoa.—Among the fossils at Cambridge are a few polyzoa, to some of which the following provisional names have been attached:—*Reptomultisparsa* cf. *megalopora* (Vine); *Heteropora* sp.; and *Tremacystia* sp.

Crinoidea.—The fossils mentioned in L. W., p. 244, as 'joints of a large round-stemmed crinoid, recalling . . . *Bourgueticrinus* . . .' have been examined by Dr. F. A. Bather and identified as *Torynocrinus*, a genus beginning in the Lower Cretaceous and not known above the Red Chalk; the Shenley form is not referable to the species found in the Red Chalk of Hunstanton. Besides those in my own collection, there are several specimens at Cambridge.

Fossils of the Greensand and Breccia associated with the Shenley Limestone.

Excepting the traces of shells in the decomposed calcareous patches, mentioned on pp. 18 & 20, the irongrit-breccia and its accompanying gritty loam and sand are almost devoid of fossils, the only examples that I have found being a specimen of 'Janira quinquecostata' and an imperfect 'Pecten' in glauconitic loam at Miletree Farm pit (fig. 11, p. 20); a small round palatal fish-tooth, and a worn fragment of the whorl of a phosphatized ammonite, probably a pebble like that referred to on p. 47, at Nine Acre pit (fig. 7, p. 16); and two or three worn casts of 'Terebratula' at

Poplars pit (fig. 14, p. 23). It is to be remembered, however, that, except under Shenley Hill, the breccia is never far below the present surface, and generally shows signs of recent weathering, as well as of an older alteration before the deposition of the Gault, so that calcareous fossils other than those embedded in the solid limestone-lenticles or in phosphatic nodules have had a poor chance of survival, even if originally present.

The thick wedge of greensand which intervened between the Gault and the breccia in former workings at Garside's pit, Shenley Hill, first exposed after our former paper was published (as described on pp. 10–13, fig. 4), was better provided with organic remains. It proved, however, a disappointing collecting-ground, owing to the patchiness of the fossils and their poor condition, aragonite shells (as in the limestone) occurring only as casts, and those of calcite being scaly and friable.

The better part of my collection of these fossils is at the Jermyn Street Museum; the remainder, along with a few collected by Walker, are still in my possession; the following rough list includes the material in both sets.

'Belemnites minimus' and 'var. attenuatus' (the most abundant fossil); cast of a large *Nautilus*, resembling 'N. radiatus'[1]; indeterminable fragment of a cast of an ammonite; 'Inoceramus concentricus' (several casts, more or less crushed, chiefly of the broad coarsely-ribbed variety found in the overlying Gault, see p. 51); 'Anomia'; several small oysters, among which Dr. Kitchin & Mr. Pringle recognize (K.P., p. 6) 'well-developed valves of *Ostrea vesicularis* Lamarck, and *O. canaliculata* (J. Sowerby)'; 'Terebratula,' some crushed, others in waterworn fragments, rather numerous, but the only one found identifiable by Walker was the specimen of *Terebratula obtusa* Sowerby mentioned previously (p. 45); many fragments of 'Serpula,' among which *Serpula antiquata* J. de C. Sowerby has been recognized (K. P., p. 6); several detached valves of cirripedes, believed to be mostly referable to *Pollicipes glaber* F. A. Rœmer and *Pycnolepas rigidus* (J. de C. Sowerby) (see K.P., p. 6); two small echinoderm-tests in very poor condition, submitted to Prof. H. L. Hawkins, and reported to be probably 'Cardiaster' or 'Holaster,' but beyond specific recognition. There are also two or three indeterminable casts of gastropods.

Among the half-dozen small but fairly well-preserved fish-teeth, Mr. E. T. Newton has recognized *Lamna appendiculata* Agassiz, *Scaphanorhynchus subulatus* Agassiz, *Sc. raphiodon (?)* Agassiz, and *Apaleodus (?)*. The three species named are recorded as occurring in the Mammillatus-beds of France, as well as in higher zones of the Gault.[2]

Fossils of the Gritty Phosphatic Nodules (Mammillatus-bed).

This fauna, discovered since the publication of our former paper, is probably the best development of the Mammillatus-fauna known in this country, but will require much specialized work, as well as further collecting, before it can be adequately discussed. It was briefly referred to in my report of the Geologists' Association

[1] Approximate determination by Mr. E. T. Newton, F.R.S.

[2] A. J. Jukes-Browne, 'Gault & Upper Greensand,' Mem. Geol. Surv. *supra cit.* p. 379; and C. Jacob, 'Etudes Paléontologiques & Stratigraphiques sur la Partie Moyenne des Terrains Crétacés dans les Alpes Françaises, &c.' Trav. Lab. Géol. Grenoble, vol. viii (1907) p. 311.

excursion in 1915 (see reference on p. 35) and has been recently described in part by Dr. Kitchin & Mr. Pringle (*op. cit.*), but is otherwise unrecorded. The following notes, based on my own collections (which I still retain), will serve as a rough indication of the main elements of the fauna. The fossils, in nearly all cases, take the form of sharp casts in the dark gritty phosphatic rock, becoming obscure and worn on the pale exterior of the nodules. Owing to the tendency of the nodules to break with a prismatic fracture, it is generally a matter of chance, even when fossils are present, whether they will be disclosed or destroyed under the hammer, and the majority of the nodules appear to carry none.

To distinguish the two principal localities, the letters G. = Grovebury pits, B. = Chamberlain Barn pit, are used after mention of the specimens.

Cephalopoda.—The ammonites recorded by Dr. Kitchin & Mr. Pringle are (1) *Desmoceras* aff. *beudanti* (Brongniart); (2) *Douvilleiceras mammillatum* (Schlotheim); (3) *Leymeriella regularis* (Bruguière); (4) *Leymeriella tardefurcata* (d'Orbigny); and (5) *Sonneratia dutempleana* (d'Orbigny). Of these, 1 & 3 are comparatively numerous and 2 & 4 comparatively rare at G. and B., mainly in small clusters of one kind. I have not myself obtained 5. I possess a well-marked fragment of 'Ammonites of interruptus-type' in gritty-nodular matrix from G., probably from the more clayey upper part of the band. Some of the ammonite-fragments preserve traces of the nacreous lustre.

Of belemnites I possess the cast of a phragmocone from G., rather large for 'B. minimus,' but apparently belonging either to this or to an allied form (see remarks above on the limestone-specimens, p. 47).

Gastropoda.—Casts of the shells of this Class are rather numerous, particularly at G., and often show good ornamentation, so that determination from mouldings should eventually be practicable. The following genera, with others, are probably represented among my specimens: 'Aporrhais,' 'Natica,' 'Pleurotomaria (?),' 'Scalaria,' 'Solarium,' 'Trochus.'

Lamellibranchiata.—Also numerous as casts, but perhaps not often specifically identifiable. I have noted the following: 'Inoceramus concentricus,' a rather small broadly-ribbed form, approaching 'salomoni,' like that in the Shenley limestone (3 specimens, G.); 'Pecten orbicularis' (several specimens, G., B.) and other pectens; 'Janira quinquecostata' (2 specimens, B.); 'Pteria pectinata' (G., B.); 'Nucula probably pectinata' (1 specimen, G.); an ornate 'Trigonia' (2 specimens, B.); 'Goniomya' (1 specimen, B.); a small striated 'Cardium' (several, G., B.); 'Cyprimeria (?)' (3 specimens, B.); 'Cucullæa (?)'; 'Panopæa (?)'; many remnants of a large shell, always crushed, 'Inoceramus' or 'Gervillia' (G., B.).

Brachiopoda.—The fossils of this Class are a subordinate element in the fauna of the nodules, and not predominant as in the limestone. They occur as casts, occasionally clustered but often singly, and are much more plentiful at B. than at G. The majority appear to belong to 'Terebratula,' of forms near to 'moutoniana' and 'biplicata var. dutempleana' (B., G.); another form may be 'Zeilleria convexiformis'; and there are probably two species of 'Kingena' (? 'newtoni,' B., and 'lima' G.). Only one 'Rhynchonella' (G.) is in my collection; also a 'Lingula' (B.).

Echinodermata.—I submitted the three casts obtained to Prof. H. L. Hawkins, who found them too ill-preserved for identification, but considered, though without confidence, that two might be small 'Pseudodiadema' (B., G.), and the third came nearer in proportion to 'Cardiaster latissimus' (G.) than to any other species (see p. 77).

Crustacea.—The claws of a large lobster-like crustacean, rather well-preserved, together with three or four less promising specimens are in my collection from B.

Among the unclassified remnants may be mentioned some unnamed polyzoa, teredo-borings, and small annelid (?) tubes, the latter sometimes riddling the nodules (B.); also some poorly preserved fragments of bone (? reptilian) (B.).

I have found no fossils whatever in the gritty clay and loam surrounding the nodules.

Fossils of the Gault.

In the next part (§ IV) of this paper, reasons will be stated for concluding that, contrary to the supposition of Dr. Kitchin & Mr. Pringle, the Lower Gault is present throughout the district under discussion, though of less thickness than at Folkestone. The division between the Upper and the Lower Gault is marked approximately, as at Folkestone, by a band of phosphatic nodules which indicate a pause in deposition at the beginning of the Upper Gault period. In the sections described in § II the Upper Gault occurs certainly in place at Harris's pit (fig. 3, p. 7) and Heath House pit; possibly also at Grovebury brickyard. It may have contributed to the top 'creep' in neighbouring sections at lower levels, but I have not seen any proof of this.

Lower Gault.—The lower beds contain few identifiable fossils, such shells as have been entombed being almost always crushed flat and, in the shallower sections, still further spoilt by weathering.

'Belemnites minimus and vars.,' and 'Inoceramus concentricus and allied forms,' are always the most conspicuous, and often the only fossils of the belt; and they distinguish it throughout the district, as also at Long Crendon (p. 42) and Littleworth (p. 40). The 'Inoceramus' shows much variation of form, sometimes attributable to crushing and slight shearing, but sometimes denoting original differences which may be of specific value; one variety is probably referable to *Inoceramus anglicus* Woods, and another, a wavy broad-ribbed form, is likely to be that mentioned by Jukes-Browne & Hill in their description of the Gault of West Norfolk,[1] as follows:—'Of the other *Inocerami* [at Muzzle], some seem certainly to be *I. concentricus*, and others resemble the larger and more compressed species which occurs frequently in the Lower Gault elsewhere, and may be identified with that known as *I. Crippsii* when found in the Red Chalk of Hunstanton.' I have obtained the same range of forms in similar condition from the 'Belemnites minimus marls' below the Red Chalk at Speeton, where they were associated with a crushed ammonite doubtfully referred to 'Ammonites interruptus.'[2]

It has been usual in stratigraphical work to 'lump' these forms under 'Inoceramus concentricus' as a term of contradistinction to 'I. sulcatus,' which can be separately recognized, however crushed, and has not, to my knowledge, been found in these lower clays.

In the recent deep section in Harris's pit (fig. 3, p. 7), the lower clays have yielded a few other crushed fossils which come within the range of possible identification. Dr. Kitchin & Mr. Pringle (K. P., pp. 13, 14) record 'the presence of small impressions of the characteristically ornamented *Nautilus deslongchampsianus* d'Orbigny' and ammonites 'poorly preserved, in a compressed condition, often consisting of little more than brown rusty

[1] On the Lower Part of the Upper Cretaceous Series in West Suffolk & Norfolk' Q. J. G. S. vol. xliii (1887) p. 572.

[2] 'On the Subdivisions of the Speeton Clay' Q. J. G. S. vol. xlv (1889 p. 604; and 'On the Speeton Series in Yorkshire & Lincolnshire' *ibid.* vol. lii (1896), table facing p. 184.

films on the bedding-planes; nevertheless, many show plainly the main features. The commonest form is closely comparable with well-known specimens,' . . . [from other places mentioned] 'variously named in museum collections as *Hoplites auritus* (J. Sowerby), *H. catillus* (J. de C. Sowerby) or *H. auritus* var. *catillus*' (see further comments, p. 78). They also mention the occurrence of *Nucula pectinata* J. Sowerby, *Pecten (Syncyclonema) orbicularis* J. Sowerby, and '*Scalaria*' *dupiniana* d'Orbigny. I have myself obtained specimens of these, except the last-named and the *Nautilus*. The ammonites are usually crushed in the horizontal plane[1]; but I found one specimen which has been crushed and spread edgewise; it appears to have been a 'Hoplites' form, with strong protuberances at the outer end of the ribs. I have also collected from the lower clays (2 to 4 feet above the base) the remains of a small fish; decomposed pyritous teredo-bored wood with traces of adherent 'Anomia (?)' and small oyster-like shells; 'Natica (?)'; and the markings of many broken bits of shell.

From the higher part of the Lower Gault under Shenley Hill I have not myself obtained any specimens in place, as this portion is so quickly obscured by slips that it is rarely accessible. It has been examined however (wholly or in part?) by Dr. Kitchin & Mr. Pringle, whose record relating to the fossils has already been quoted (fig. 3, description, pp. 7–8). Somewhere in this part, probably not far below the Upper Gault nodule-bed, the clays must contain some ammonites partly infilled with concretionary matter and thus preserved in an uncrushed condition, as I have collected several good fragments in this state, mostly of the 'Ammonites auritus' and 'A. splendens' types, from spoil removed from the middle of the slips; and I have a specimen of the same kind (either 'auritus' or 'lautus') from Chance's pit, obtained in 1904 from a quarryman, and said to have been found in place.

Fragments of the 'splendens' ammonite in the same condition may still be picked up on the clay-slopes of the old Heath House pit (p. 29).

The other sections in the lower clays around Shenley Hill have yielded little beyond 'Belemnites minimus' and 'Inoceramus concentricus'; and it is noteworthy that the Littleworth brick-pit, from which Jukes-Browne records Lower Gault ammonites (p. 39), has yielded to me nothing more than the same 'Belemnites' and 'Inoceramus' in the present weathered exposure.

From the lower clays of the Grovebury brickyard I have collected at various times the following fossils among others, mostly as fragments, but hard and uncrushed, the majority being from the band of small brown nodules described in the section (p. 34):—'Ammonites interruptus' (1 specimen); 'A. auritus' (3 specimens); 'A. splendens' (5 specimens); 'Hamites' (3 specimens); 'Belemnites minimus'; 'Dentalium decussatum' (1 specimen); 'Natica'; 'Nucula'; etc.; and from larger nodules probably occurring in the upper part of the section—'Ammonites rostratus' (1 specimen, good); 'A. varicosus' (2 specimens); and 'Inoceramus sulcatus or subsulcatus.'

Upper Gault.—Except the few specimens from Grovebury brickyard just mentioned, and a few representing the same species and in the same condition found on the weathered slopes of Heath House pit, my collection of the Upper Gault forms has been obtained entirely from the fossiliferous band with phosphatic nodules near the top of Harris's pit (fig. 3, p. 7). The following

[1] In the first sketch of the section in my notebook, dated June 2nd, 1902, made just after the discovery of the fossiliferous limestone, my description of the Gault reads:—'Gault clay, Inoceramus concentricus, Ammonites interruptus, &c., thickness: 5 to 8 feet.' For some reason which I cannot now recall, but probably because I had not carried away specimens for reference, and was (quite rightly) doubtful of my field-determination, I omitted reference to the ammonite in the paper published in 1903. The forms that I saw may have been like those now described.

rough determinations are poorly representative of the fauna, and the list could certainly be much extended:—

'Ammonites rostratus and vars.' (many); 'A. auritus and vars.' (both in nodules and soft clay); 'A. varicosus' (few); 'A. splendens and vars.'; 'A. near cœlonotus'; 'A. studeri'; 'A. lautus?'; and others; 'Hamites'; 'Belemnites minimus' (many). 'Inoceramus concentricus' (both in nodules and soft); 'I. subsulcatus' (one specimen in black phosphate); 'I. sulcatus' (nodules and soft); 'Nucula pectinata' (soft); 'Plicatula' and 'Ostrea'; 'Dentalium' (many); 'Scalaria,' 'Solarium,' and other univalves; 'Pentacrinus' (in patches).

IV. Classification, Structure, and Conditions of Deposition.

The sequence of beds exposed in the sections described may be tabulated in downward order as follows:—

Formation.		*Composition.*	*Locality.*	*Thickness in feet.*
Post-Glacial.	(Z.)	Soil, downwash and 'creep.'	All sections.	1 to 4
Glacial.	(Y.)	Boulder-clays with associated and later gravels.	Absent in some places: best seen at Claridge's pit (fig. 15) and Littleworth (p. 39).	0 to 20
Gault (part of).	(5)	Upper Gault, lowest part only: pale blue-grey marly clay, with numerous corroded phosphatic nodules (5a) at or near the base.	Harris's (fig. 3), Heath House (p. 27) and Grovebury brickyard (p. 34).	0 to 6 (seen)
	(4)	Lower Gault; dark grey-blue clays with small brown-coated nodules; generally becoming gritty near the base (4a).	All sections.	up to 18
Basement beds.	(3)	South of Leighton. Gritty glauconitic clay and loam (3b) with occasional worn fragments of ironstone; sparsely studded with fossiliferous gritty phosphatic nodules. North of Leighton. Similar material more coarsely gritty (3b) associated with, and in places thinning out upon or under (3a) a band of irongrit-breccia with ferricrete 'pans' and lenticles (3); and with calcrete patches thickening locally into lumps or tables of fossiliferous limestone.	South—Grovebury pits (fig. 17, p. 33) Intermediate—Chamberlain Barn pit (fig. 16) North—All Shenley pits; Poplars (fig. 14), Claridge's (fig. 15), and Heath House pits: also West—at Southcott (p. 38), Littleworth (p. 39), and Long Crendon (p. 40).	1 to 5
		Uneven surface of erosion.		
Lower Greensand Series (part of).	(2)	The Silty beds: regularly bedded ashy-grey silts, carbonaceous and ferruginous loam and clay, and some sand.	Present in some Shenley sections and northwards; absent southwards.	0 to 12
		Plane of erosion.		
	(1)	Leighton Sands: strongly cross-bedded coarse sands. North of Leighton: almost purely siliceous 'Silver Sand' with local patches of ferruginous staining and induration (1x). South of Leighton: less pure, speckled, brownish or greyish sands, rarely showing staining or induration.	All the pits around Leighton.	

The general dip of the Cretaceous sequence is south-eastwards at a low angle; the plotting of continuous sections brings out, however, some local anomalies due, not to tectonic structure, but to the mode of formation of the deposits. Thus, a long section drawn north-eastwards, on the general strike of the Gault,[1] from Chamberlain Barn pit through the Shenley Hill pits to Poplars pit, a distance of nearly 2 miles, shows a rise of 55 feet in the floor of the Basement beds in the first 1350 yards (between Chamberlain Barn and Harris's, Shenley) and then a fall of about 20 feet in the further mile (between Harris's and Poplars). If the initial rate of rise had been continued to the north-eastern end of the section, the base of the Gault would have been some 70 feet higher at Poplars than at Harris's, instead of being 20 feet lower; so that the floor at this end of the section falls about 90 feet below the plane of its southern part. Calculating by the same method in the reverse direction, from north-east to south-west, we find that the floor at Chamberlain Barn is about 70 feet lower than the plane prolonged from the northern half of the section. The gentle slopes of the low arch thus indicated are somewhat accentuated on both sides towards its crest, which is situated under Shenley Hill and has been cut across by the north-and-south range of sandpits. The top of the arch shows distinctly in the combined section of these pits on the natural scale (fig. 12, p. 22); but, owing to the vertical component being so small in comparison with the horizontal, it has been found impracticable to reproduce the full-length section from Chamberlain Barn to Poplars on a small scale, without such excessive vertical exaggeration as to destroy its utility.[2]

It is clear that the Basement beds and Gault were laid down on an uneven surface, which may partly have reflected the original heaping-up of the Lower Cretaceous sand-banks, but appears to have owed still more of its irregularity to the erosive action of sea-currents during the early stages of the Upper Cretaceous transgression. The conditions, from late-Lower Cretaceous times

[1] The conjectural boundary of the Gault on the Old Series 1-inch Geological Survey map (Quarter-Sheet 46 N.W.) in the area north-east of Leighton has proved to be incorrect in many places, as was inevitable from the obscurity of the ground, the slipping of the clays, and the difficulty of distinguishing between Boulder Clay and Gault from surface-indications only. The Gault boundary near Heath is now known to lie at least half a mile farther west than shown. The district was partly re-surveyed on the 6-inch scale some 30 years ago, and the boundary corrected so far as was then possible; the results have not been published, but are available for reference on manuscript 6-inch maps in the Geological Survey Library at Jermyn Street.

[2] For the same reason, a still longer section, from the Grovebury pits to Poplars, intended to illustrate the upward curve of the Gault and the accompanying changes in the character of the Basement beds, has been found unadaptable for reproduction. Its purpose can be served by a combination of the small figured sections, in the following order (south-west to north-east):—figs. 17, 16, 4, 3, 6, & 14. All these are to the same scale, and their relative position is shown on the sketch-map (fig. 1, p. 2).

onwards until well into the Upper Cretaceous, were very favourable for the production of such currents, since we have evidence, both stratigraphical and palæontological, for the existence of a strait in this quarter, connecting a broad Anglo-French basin on the south with a broad Anglo-Germanic basin on the north.[1]

It is common knowledge that borings in Hertfordshire and the Eastern Counties have proved the presence of an eroded Palæozoic floor almost immediately below the Gault, indicating a near shore-line to the eastward; while immediately west of Leighton there is a double transgression and unconformity, first of the Lower Cretaceous Sands onto the Oxford Clay, and then of the Gault across the Sands and likewise across the Jurassic sequence from the Oxford Clay upwards, proving an uplift and emergence of a shore-line in that quarter also; and the shallow-water current-bedded Leighton Sands, accumulated in the strait, have their main development between these borders.

The Silty beds (2).—I do not propose in this communication to deal further with the Leighton Sands (1), but some discussion of the Silty beds (2) is necessary, as these beds have been stated by Dr. Kitchin & Mr. Pringle to contain the gritty phosphatic nodules and to be the parent-bed from which these nodules have been washed into the Basement beds of the Shenley sections (K.P., pp. 55–8). They propose to divide the Silty beds seen at Miletree Farm (fig. 11) into two parts, describing the upper 8 feet as 'the *tardefurcata* bed,' though acknowledging that they failed to find any palæontological evidence for the correlation (see *postea*, p. 69). I am compelled to dissent from this interpretation, since, as previously mentioned (p. 21), I have been unable to find a single nodule of the Basement-bed type in the Silty beds. The only nodules that they have yielded to my search are of the sandy ferruginous type (probably once pyritous), and of the tabular clay-stone type, both peculiar to these beds and quite different from the gritty phosphatic concretions. It is true that at Miletree Farm and elsewhere one can occasionally see, beneath the iron-grit breccia, small hollows of erosion scooped out of the Silty beds and filled in with the gritty glauconitic loam of the Basement beds, in which are embedded a few gritty phosphatic concretions, generally of small size; but these clearly belong to the Basement beds, and not to the Silts. The gritty loam of the Basement beds is the proper and original matrix for nodules of this kind; and the same association of matrix and nodules is characteristic of the Mammillatus Beds of the North of France (p. 58). On the other hand, the silty carbonaceous beds are of a type occurring in exactly the same relation-

[1] Jukes-Browne postulated the existence, and traced the probable course of this 'narrow strait or channel, through which a strong current ran from the northern to the southern sea' during the time precedent to the Gault, in 'The Building of the British Isles' London, 2nd ed. (1892), p. 277 & pl. x; see also his memoir on 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, p. 402.

ship to the coarse sands at Aylesbury,[1] and among the Lower Greensands in other parts of England, as, for example, around Ash Wicken in Norfolk[2]; and such beds are generally, perhaps always, devoid of phosphatic concretions, rarely yielding any fossils except bits of plants. The composition and mode of occurrence of these deposits are suggestive of estuarine conditions produced by the local influx of land-waters.

In the present instance, the deposits indicate a temporary cessation of the strong currents which had heaped the Leighton Sands into banks. The Silty beds rest sharply on an eroded and somewhat undulating surface of these sands, and appear, from their rapid variation in thickness, to have filled up the broader hollows between the banks. They are confined to an area lying north of a north-west and south-east line drawn from the northern end of the village of Heath[3] to the Shenley Hill pits; and, although their present termination along this line is irregular, and has to some extent been determined by the renewed erosion which preceded and accompanied the formation of the Basement beds, there are clear indications that the southward limit of their original basin of accumulation lay in this neighbourhood. This limit approximately coincides with the crest of the low arch of the Gault and its Basement beds above-described; and it is along this axis that all the beds undergo the changes in composition and structure which have lent so much interest to the exposures.

The core of the belt is composed of cross-bedded 'Silver Sand,' which appears here to have been heaped up in a long bank or plexus of banks forming a shoal, with deeper water on both sides, the depression on the northern side being subsequently filled in by the Silty beds.

It is all along the top of this old shoal that the patches of induration occur, by which the upper part of the Sands is converted in places into massive bosses of iron-grit and quartzite, this condition being prevalent in the pits ranging from Miletree (fig. 10) on the east, through Nine Acre (figs. 7, 8) and Garside's (fig. 4) to the old Heath House pit (p. 29) on the west (see map, fig. 1, p. 2). In discussing this peculiar induration in our previous paper (L.W., pp. 240–41), we showed that it must have been effected, in part at any rate, before the deposition of the Gault, as the breccia below the Gault was composed principally of waterworn fragments of this material, some encrusted with adherent oysters and serpulæ. The conclusion has been confirmed by all my later

[1] A. M. Davies, 'Contributions to the Geology of the Thame Valley,' Proc. Geol. Assoc. vol. xvi (1899) p. 49. See also 'Special Reports on the Mineral Resources of Great Britain, vol. vi, Refractory Materials, &c.' Mem. Geol. Surv. 1911, p. 180.

[2] 'Geology of the Borders of the Wash' Mem. Geol. Surv. 1899, pp. 17–18.

[3] Besides the sections dealt with in § II, the Silty beds are seen to a depth of 6 or 7 feet at the top of a big sandpit ('Stone Lane pit') 700 yards north-north-east of Claridge's pit (fig. 15) or 250 yards beyond the northern border of the sketch-map (fig. 1), at the turn of the road leading from Reach to Woburn; they form the capping of a deep section in the coarse Sands.

observations, particularly by the new facts disclosed in Garside's pit, as already described (pp. 10–13) and the similar features displayed in the Nine Acre and Miletree pits (pp. 16–19). It is significant that this massive induration should occur mainly in the neighbourhood of the boundary of the Silty beds; and it is at least probable that the mineralizing solutions may have been derived in the first instance from the mixed and unstable materials of these beds. In shallow-water deposits of this type, if a slight elevation ensued after their deposition, so that they were brought under the influence of weathering, the waters percolating from the surface would become charged, as they still often are, with mineral matter in solution, which might be redeposited in the cleaner beds below.

But whatever may have been the cause of the induration, we can see from the sections that it had become effective at an early date; so that when, by another change of conditions, there was a sharp renewal of current-action on the shoal, and possibly wave-action also, during the stages ushering in the great marine transgression of Upper Cretaceous times, the old sand-banks yielded very unequally to the attack. The shoal, protected by its irregular capping of iron-grit, was scoured into crags and rocky ledges, which were undermined along their edges, and broken down into a breccia, but continued to persist in patches as a dissected reef, until, with the deepening of the water, the severity of the attack died down and passed gradually into the tranquil conditions required for the deposition of the Gault clays. In the sketch-map (fig. 1, p. 2) the cross-road from Heath past Shenley House to Clipstone runs nearly along the southern margin of the old reef.

It has already been pointed out how closely this sequence of events agrees with that occurring during the same period in North-Eastern France, where the floors of Palæozoic and Mesozoic strata underlying the Upper Cretaceous rocks have been similarly scoured and guttered.[1] The conditions are also repeated, on a modified scale, at the base of the Red Chalk along the western edge of the Yorkshire Wolds (see p. 64).

The Basement beds (3).—The difficulties and misunderstanding which have arisen in respect of the correlation and classification of the peculiar and variable beds immediately underlying the Gault clays in the sections described, have been caused mainly by the difference between the aspect of these beds in the Grovebury sections and in the Shenley and other sections about 2 miles farther north. This difference, however, is now bridged by the association of the two separate types of deposit in the intermediate section at Chamberlain Barn pit; and my original surmise as to the relationship of the types[2] is justified. The difference is mainly due to the persistence, for some time, of shoal-water and reef-

[1] See footnote and reference, *ante*, p. 18: also C. Barrois, 'Terrain Crétacé des Ardennes, &c.' Ann. Soc. Géol. Nord, vol. v (1878) pp. 278–80.

[2] Proc. Geol. Assoc. vol. xxvi (1915) p. 310.

conditions on the north and of deeper water with strong and steady currents on the south; and it must be remembered that a distance of 2 miles at right angles to the trend of a coast-line gives ample space for great variation in the character of marine sediments.

About the beds of the Grovebury type, there is no question. In their position, lithological characters, and fossil contents, they are recognizable with certainty as the equivalents of the 'Mammillatus Beds' of English and French geologists. These beds are everywhere notoriously variable, and their exceptionally wide exposure in these sections affords an unusual opportunity for studying them in detail. The beds are of about the same thickness as at Folkestone, but preserve, in their well-distributed nodules, a somewhat fuller, though still imperfect, record of the life of the period, agreeing more nearly in this and other respects with their equivalents in the North of France, particularly in the region of the Argonne. At Folkestone, the fossiliferous phosphatic nodules are almost entirely confined to one band, in which they have been segregated into clusters,[1] and the accompanying glauconitic sandy deposits contain scarcely any fossils. At Leighton, although again it is unusual to find anything preserved in the glauconitic matrix, the phosphatic nodules stud the beds at all levels, and contain a wider range of fossils. It is clear that the phosphatic concretions have been formed in a matrix like that which now surrounds them; but they often show traces of submarine corrosion and wear, indicating that they have lain exposed at times on the sea-floor. They were formed quickly enough to enclose in a fresh state the organic relics which lay on the sea-floor, nearly all of which have perished utterly where not thus enclosed. All the circumstances imply a lengthy period of very slow deposition, with bottom-currents strong enough at times to disturb and winnow the sea-floor, but not strong enough to sweep away the nodules.

The resemblance of these nodules to the coquins de sable occurring, sometimes segregated into a band and sometimes scattered, in the Mammillatus Beds of the Argonne is remarkably close; as may be judged from the following extracts from the description of the French sections by Prof. C. Barrois[2]:—

> 'Ces nodules, appelés coquins par les habitants du pays, ont la forme de rognons arrondis, tuberculeux, ils sont compacts, noirâtres, et d'une couleur généralement plus foncée à l'intérieur qu'à la surface. . . . ces nodules sont rarement homogènes, ils sont pénétrés et souvent recouverts à la surface de gros grains de quartz, de glauconie. . . . . Les ouvriers distinguent parfaitement ces nodules qu'ils appellent coquins de sable, des nodules de la gaize qu'ils appellent coquins riches':—

And it may be remarked here that at Leighton a corresponding

[1] See my notes on the Copt Point (Folkestone) section in Jukes-Browne's previously cited memoir on the Gault, &c. (Mem. Geol. Surv.) p. 73.

[2] 'Sur le Terrain Crétacé des Ardennes & des Régions voisines' Ann. Soc. Géol. Nord, vol. v (1878) p. 277.

difference exists between the 'Mammillatus' nodules and those at the base of the Upper Gault.

Prof. Barrois's comments[1] on the manner of occurrence of the nodules are also very apposite. Referring to the segregated nodules at the top of the Mammillatus Beds, he writes:—

'Les lits qu'ils forment aujourd'hui dans ces sables ne sont pas d'origine première; ces nodules ont pris naissance isolément dans le dépôt des sables, puis des affouillements locaux et sous-marins ont déchaussé en divers points ces nodules, ont enlevé le sable qui les empâtait et laissé sur place sans les rouler les nodules et les fossiles trop lourds pour être enlevés. En un mot, je crois les lits de nodules de phosphate de chaux (coquins de sable), remaniés sur place, et indépendamment les uns des autres:' [and, after figuring and describing examples, he adds] 'on doit croire ici à un remaniement sur place; c'est-à-dire, à l'enlèvement des parties tenues argilo-sableuses et à l'accumulation conséquente des nodules plus lourds.'

The same conclusion with regard to the mode of accumulation of the Cretaceous phosphatic nodule-beds has been expressed by many English investigators.[2] Yet, in spite of all, one often still finds that such nodules are postulated to be 'derivative' or 'derived pebbles' as a matter of course, particularly if their fossil-contents happen not to agree with palæontological preconceptions. The possibility of the nodules becoming derivative pebbles is obvious, though their material is not of a kind to sustain much hard wear; but the weight of existing evidence demands that they should be assumed to be in place, or, at least, 'remaniés sur place,' unless the contrary can be proved; and not *vice versa*.

It has long been recognized that phosphatic nodules are indicative of slow sedimentation (see *ante*, p. 9); and if there has been, in addition, a repeated washing-away of their matrix, with resultant concentration of the nodules, we may expect to find, as we generally do find, that the organic relics contained within narrow bounds represent a condensed fauna which elsewhere may tenant a great thickness of sediments of another type. The nodule-bearing Mammillatus Beds of the North of France are represented in North Germany by a fuller sequence which is capable of subdivision, and the later German investigators, on the strength of this, have thrown aside the French classification, and have adopted a new scheme of zones. In their general scheme our Upper and Lower Gault become 'Upper Gault'; our Mammillatus Beds become the upper part of the 'Middle Gault,' with a lower part not yet recognized in this country; and most of our Lower Greensand

[1] Ann. Soc. Géol. Nord, vol. v (1878) p. 278.

[2] As, for example, F. G. H. Price, 'The Gault' 1879, p. 9; and 'Probable Depth of the Gault Sea' Proc. Geol. Assoc. vol. iv (1875) p. 269. A. J. Jukes-Browne, 'The Cambridge Gault & Greensand' Q. J. G. S. vol. xxxi (1875) p. 282; (with W. Hill) 'The Lower Part of the Upper Cretaceous Series in West Suffolk, &c.' *Ibid*, vol. xliii (1887) p. 572; and 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, p. 428. G. W. Lamplugh, 'On .... the Speeton Clay' Q. J. G. S. vol. xlv (1889) pp. 584, 588; 'The Speeton Series in Yorkshire & Lincolnshire' *Ibid*. vol. lii (1896) pp. 195–99; 'Lower Cretaceous Phosphatic Beds, &c.' Geol. Mag. 1904, p. 551, and Rep. Brit. Assoc. 1904, p. 548.

becomes 'Lower Gault'[1]; while in the new zonal scheme the Mammillatus Zone is divided between an upper 'Zone of *Leymeriella regularis*' and a lower 'Zone of *Leymeriella tardefurcata*.' Both zonal ammonites are common in the Mammillatus Beds of Northern France, and both have now been found also in the equivalent beds around Leighton Buzzard, *L. regularis* being indeed the most plentiful (or rather, least rare) ammonite of these beds.

Ignoring the old term 'Mammillatus Beds,' Dr. Kitchin & Mr. Pringle have termed the Leighton deposits 'the *tardefurcata*-beds,' which seems to me to be at once unnecessary and unjustifiable, since this is the name of the lower German zone only, whereas both ammonites are present and, so far as we yet know, are inseparable, as in France. There is really no excuse for introducing this complexity when the old term, with which we have become familiar, fits the case more conveniently.

The discovery of these species at Leighton appears to be their first definite localization in England, though *tardefurcata* has been vaguely referred to as occurring in our country.[2]

The term 'condensed beds' might be usefully applied, in a comparative sense, to deposits of this type[3]; and it is evident that such beds cannot be subjected to the same refinement of subdivision as the synchronous deposits of greater thickness and more regular sedimentation. As we shall see, not only the Mammillatus Beds, but the whole of the Lower Gault is more or less 'condensed' in this region, as it is also in many parts of the North of France, with the natural result that the succession of zones traceable in it at Folkestone has been found inapplicable here.[4]

The big concretionary lumps which occur at the very top of the

[1] E. Stolley, 'Die Gliederung der Norddeutschen Unteren Kreide' Centralblatt für Min. &c. 1908, pp. 243–47 (note also his remarks on French and other nomenclature, pp. 247–50); and, later, E. Stolley 'Beiträge zur Kenntnis der Cephalopoden der Norddeutschen Unteren Kreide . . . 1. Die Belemniten des Norddeutschen Gaults (Aptiens & Albiens)' Geol. Palæont. Abhandl. n. s. vol. x (1911) p. 20; this classification is reproduced, with slight modifications, by W. Kilian in 'Lethæa Geognostica,' pt. 2, vol. iii, 'Kreide,' sect. 1, 'Unterkreide,' 3te Lief. 1913, p. 327.

[2] C. Jacob ('Étude sur quelques Ammonites du Crétacé Moyen' Mém. Soc. Géol. France, Palæont. No. 38, 1907), in his description of *Leymeriella tardefurcata*, remarks: 'Cette espèce est généralement abondante dans toutes les localités où l'on trouve la zone de l'Albien qu'elle caractérise: Angleterre, Bassin de Paris, Allemagne, Jura, Alpes françaises et suisses, etc.'

[3] J. F. Blake would have included some of these 'condensed beds' under his term 'Aggregate Deposits' (see his acute and suggestive paper 'On Aggregate Deposits & their Relations to Zones' Geol. Mag. 1898, pp. 481–88); but he defines his term as essentially implying lateral transportation, 'the etymology of the word connoting only the assemblage of materials that have been moved horizontally, like a flock of sheep, over the surface of the ground' (p. 484). By the term 'condensed deposit' I wish to express the idea of the heavier materials on the sea-floor having been let down vertically without much lateral shift. The same idea is conveyed by Barrois's term 'remaniés sur place.'

[4] A. J. Jukes-Browne, 'Gault, &c.' Mem. Geol. Surv. *supra cit.* pp. 45, 69.

Sands immediately below the Mammillatus beds at Grovebury (fig. 17), Chamberlain Barn (fig. 16), and in one or two places at Nine Acre are quite different in aspect from the fossiliferous nodules of the overlying beds, and have as yet yielded no fossils whatever, except some vague tubular markings. They are generally composed internally of a dense smooth phosphate, pale buff, deepening centrally to dark grey or blackish, but often mottled with crimson patches, while outwardly they merge without definite boundary into their sandy matrix. They may represent only the effect of phosphatizing solutions percolating into the sands from the overlying beds; but in some places, particularly in the section shown in fig. 17, they appear to form a distinct band, separable from the beds above and below. They are only seen where the top of the Sands has been protected from weathering by a fairly thick cover of Basement beds, with which they are certainly in some way connected. When they first made their appearance, some years ago, in the Grovebury sections, I thought that they might prove to be the local equivalents of the Shenley limestone-lenticles, but in the absence of fossils no such proof is forthcoming.

The ferruginous components, so conspicuous in the Basement beds farther north, are represented at Grovebury only by occasional waterworn flat fragments of iron-grit (the largest to come under my observation being 6 inches in diameter), presumably derived from the shoal on the north, and by a few small iron boxstones and thin wisps of imperfect ferricrete. These are the final indications of the fading-out of the breccia.

The correlation of the Grovebury and Chamberlain Barn sections is beyond question (figs. 17 & 16). The pronounced breccia-band in the latter marks the closer proximity of the shoal-reef, and proves its pre-existence and sharp erosion during an early stage in the accumulation of the nodule-beds. The large slabs of iron-grit and other detrital material of the breccia are set in a matrix of gritty glauconitic loam indistinguishable from that of the overlying beds, and phosphatic nodules occur occasionally in the breccia as well as above it. The patches of calcrete and the iron boxstones are further indications of its approach to the condition of the irongrit-breccia of Shenley, and the only marked difference is the absence of unbroken tabular iron-pan. All the circumstances point to the coarse material having travelled down the sloping floor of the sea from no great distance, and having come to rest in deeper water. Just as the Grovebury type of deposit has its closest lithological analogue in the Mammillatus Beds of the Argonne, so the breccia-band of this and other sections has its nearest physical analogue in the 'Tourtias' of the Flanders country, these 'Tourtias,' as their investigators have long recognized, marking a condition of accumulation and not a fixed time.

From the Chamberlain Barn section we pass to the old south-western working at Shenley (Garside's pit, figs. 4 & 12, pp. 11 & 22) about 1100 yards distant, and find here a cleaner calcareous glauconitic sand, devoid of large nodules, with a strong 'pan'-bound

breccia at its base, banked around the crags and upon the slopes of the reef. It has been argued that the sand here is Upper Greensand in an inverted position, but every feature of the section tells against the supposition. The peculiar breccia, so unlike any other deposit known in the district, is unquestionably linked with that of Chamberlain Barn, known to lie at the bottom of fossiliferous Mammillatus beds; and the difference in the composition of the beds above it is no more than these inherently variable beds display from place to place in other sections. In this particular instance the reason for the difference is not far to seek, as the section shows that the sand was accumulated among the crags on the side of the reef, and presumably was thus sheltered from the full sweep of the currents. The calcareous particles mixed with the sand denote the wastage of the neighbouring shell-bank, probably already partly consolidated. It is possible that some of the sand at this spot may be equivalent in time to some of the lowest Gault clays of the deeper-water areas, but it is certainly older than the clays of the immediate neighbourhood, and may be placed most conveniently, as a whole, in the Mammillatus Zone.

In the Garside's-pit section we reach the margin of the area in which the fossiliferous limestone occurs, and the beds of the Grovebury type are wanting or found only in hollows and pockets. The description of the limestone and its concomitants in our previous paper has stood the test of all my later observations, and needs no modification in any essential. The conclusions as to its stratigraphical position and mode of origin have been strengthened by the new evidence, and it will be shown (in § V) that the recently-urged palæontological argument for a hypothetical inversion of the beds in relation to the Gault has no foundation in fact. The discovery of 'Ammonites regularis' and 'A. cf. beudanti' in the limestone (p. 47) along with some other fossils, has afforded a palæontological link with the Grovebury type of Basement beds, while its stratigraphical association with the same beds is now established by the new Chamberlain Barn section and that at Southcott. In our previous discussion we suggested that the Shenley fauna might be somewhat older than that of the Mammillatus Bed of Folkestone. It is now apparent, however, that the bed at Folkestone does not represent the whole Zone; and the Shenley limestone should fall within the Mammillatus Zone in the broader sense. I gave reason, in the same discussion, for holding that the English Mammillatus beds should be retained in the Lower Greensand, their original classification, on the grounds of priority and of stratigraphical convenience[1]; but, as then stated, I regard these matters of conventional classification as of secondary con-

[1] It will be noticed that, in his account of the Long Crendon section (quoted on p. 41), Jukes-Browne classed the thin ferruginous beds below the Gault as 'Lower Greensand,' on stratigraphical grounds; but, if he had been aware that they contained fossils linking them with the Mammillatus beds, he would have united them with the Gault as 'Upper Cretaceous,' since he adhered to the French classification of the Mammillatus Zone.

sequence if the actual sequence be not prejudiced by them. The French geologists always class the Mammillatus Zone with the Gault as Albien, therefore Upper Cretaceous; the German authorities, as mentioned above, place the zone in the Middle Gault, and carry the whole of the Gault into the Lower Cretaceous.

It is unfortunate that the opportunities for studying the fossiliferous limestone have become very restricted, and are likely before long to be lost altogether. The rock is only preserved in an unweathered condition where the cover of Gault is thick, which implies costly working to reach the Silver Sand, particularly as the limestone and its associated irongrit-breccia and loamy beds have also to be removed as 'spoil.' The sporadic distribution of the lenticles adds a further element of uncertainty; hence a visitor to the section can no longer count upon the probability of finding the bed exposed. On the other hand, the range of sections exhibiting the irongrit-breccia has been greatly enlarged since our former communication, and the opportunities for examining it are being constantly extended, while the recent appearance of a small lenticle of the limestone in the breccia at Poplars pit shows that any of these sections may make further disclosures of the rock.

Sufficient information respecting the local peculiarities of the breccia and its continuity over the northern area has been given in the preceding sections and descriptions; the occurrence of a similar band at the same horizon many miles away to the west, at Littleworth and Long Crendon, has also been described (pp. 39–44); and it remains only to discuss the general bearing of the facts. By Dr. Kitchin & Mr. Pringle the band has been termed 'Basal bed of the Upper Gault,' on the supposition that there is a sharp overlap of the Upper Gault onto the Lower Greensand in the Shenley area; their opinion depends upon their interpretation of the Gault sections, with which I cannot agree, for reasons presently to be stated. The period of formation of the iron-grit 'pans' has also been brought into question by the same writers, who claim that those which enclose the limestone must be of post-Glacial date, a necessary corollary to their opinion that the limestone has been transported to its present position by Glacial agency. We will consider the evidence on this point first.

Since the larger fragments in the breccia consist almost entirely of flat pieces of iron-grit, more or less waterworn, and occasionally encrusted with marine organisms (L. W., p. 241), it is certain that some of this material was in existence in practically its present condition when the breccia was formed. The fragments, like the still-continuous 'pans,' show wide variation in texture and composition, ranging from an almost pure dense iron-ore (hematite) to a coarse grit with comparatively little iron; and the implication that the fragments have been derived from the breaking-down of pans similar to those still unbroken is borne out by sections (as, for example, figs. 7, 8, & 10) in which stages of the process of disruption are visible, and by others (figs. 4, 8, 9, & 10) in which the contemporaneous existence of ironstone crags is proved. The

evidence of scouring and abrasion, to be noted on the upper surface of the top pan wherever it has remained unbroken, also shows that this layer was in existence as a hard bed before the covering strata were deposited. Most of these points were duly noted in our previous communication, and all have been confirmed by later observations. That there may have been further segregation of iron resulting from the weathering of the deposits in comparatively recent times also received early consideration (L. W., p. 240), and more was then assigned to it than the later evidence indicates as probable. The main effect of recent weathering appears to have tended towards the decomposition of all except the more stable components of the breccia, and not to the induration of any part of it. Some of the patchy ferruginous discoloration of the highly porous Silver Sand probably marks the course of the iron-solutions percolating from decomposing breccia in late times.

It is remarkable that this condition of iron-concentration is exhibited in almost all the shallow-water deposits accumulated in this country towards the end of Lower Cretaceous times and during the early stages of the Upper Cretaceous transgression. Thus, in the Isle of Wight, we find at this horizon the Carstone or Ferruginous Sands [1]; in West Sussex, the crimson grit—a thin band of hard ferricrete [2]; in the Vale of Wardour and other parts of Wiltshire, gritty ferruginous beds [3]; in Oxfordshire, the Hurst-Hill and Boar's-Hill Sands [4]; in Norfolk and Lincolnshire, the Carstone [5]; in Yorkshire, at the western edge of the Chalk Wolds, patches of ferruginous sand, and, where these are absent, an ironstone breccia in the attenuated Red Chalk.[6] It has been observed in all these cases that the ferruginous beds hang in stratigraphical continuity with the overlying Upper Cretaceous rocks, but have usually a sharp and sometimes transgressive basement.[7] Like the Tourtias of Flanders, they are evidently not strictly synchronous in separate districts, but mark a condition of the encroaching shallow sea, when the land was only in part submerged and still yielded much waste to the current-swept channels and straits which were gradually expanding around its remnants. In some cases the present aspect of the beds may be due to the decomposition of original glauconite long after their accumulation; but often it can

The following references might be greatly expanded, but will serve as general indications to the literature:—

[1] 'Geology of the Isle of Wight' Mem. Geol. Surv. 2nd ed. (1889) pp. 52–59.

[2] 'Geology of the Country near Chichester' *Ibid.* 1903, pp. 12, 16.

[3] 'Cretaceous Rocks, &c. vol. i—Gault & Upper Greensand' *Ibid.* 1900, p. 228; and 'Geology of the Country South & East of Devizes' *Ibid.* 1905, pp. 8–12.

[4] 'Geology of the Country around Oxford' *Ibid.* 1908, pp. 75–78.

[5] A. Strahan, 'On the Lincolnshire Carstone' Q. J. G. S. vol. xlii (1886) pp. 486–92.

[6] 'Geology of the Country North-East of York & South of Malton' Mem. Geol. Surv. 1884, pp. 25–26; and 'Special Reports on Mineral Resources, &c. vol. xii: Iron Ores (*contd.*)—Bedded Ores, &c' *Ibid.* 1920, pp. 207, 208.

[7] A. Strahan, *op. supra cit.* pp. 489–90, and 'Geology of the Isle of Wight' *op. supra cit.* p. 53.

be proved that their ferruginous condition was attained before they were covered by the newer sediments. In several instances it may be surmised with probability that the beds were originally glauconitic, and that the decay of this constituent was brought about not long after their deposition, by some physical change by which the material was exposed to weathering agencies. It is likely enough that slight oscillations accompanied the general downward movement of the period, and that the shoals and sand-banks of the shallow sea may at times have been raised above low tide, if not above all tides.[1] The iron-pan and breccia above the Shenley shoal suggest conditions of the lateritic type, possibly in operation above or between tide-marks, or in very shallow water. I am not qualified to speculate upon the chemical history of the processes; but an examination of the structures in the field shows clearly enough that the iron-pan has been produced, not directly as a precipitate or sediment, but by the replacement of some constituents of an existing deposit and the cementation of the rest. All the evidence goes to show that it was in practically its present condition before the clays of the Gault were laid down, and that, wherever it remained unbroken, it protected the beds beneath it from the scour of the currents which swept the strait until well into Gault times.

During this heavy scour no sediment could lodge on the bare smooth ironclad surface of the reef; consequently we find that the glauconitic sands wedge out on its flanks (fig. 12, p. 22) and that the gritty glauconitic loams, etc., with their phosphatic nodules. are preserved only in the hollows and gullies by which the edge of the reef is broken, and in the tract on the south where the water was deeper. Fortunately, the lenticles of limestone on the top of the reef afford us a glimpse of its fauna at the beginning of these events, a fauna consisting for the greater part of forms adapted for rocky ground, such as the anchoring brachiopoda and the usual mollusca, echinoderms, and crustaceans of the 'reef-facies'; but, after this, the sequence is locally broken until the waters above the shoal became deep enough and still enough to allow a clay-mantle to be spread over it.

The Gault Clays (4 & 5).—Having supposed that the Gault of the district, as a whole, had been already fairly well elucidated by the work of previous observers, particularly of Jukes-Browne & Hill,[2] I have not, until recently, devoted much attention to any except its lower portion. However, in consequence of the statement

[1] Many features of these Basement beds have their analogues in the ferruginous Dogger at the base of the Oolites in Yorkshire, which shows the same local variability on a bigger scale, the same association and changes between ferruginous and phosphatic-nodular beds, the same 'Tourtia'-like conditions in its relation to the underlying strata, and similar palæontological evidence for 'condensed' deposition. The patchy local concentration of iron-ore in the Dogger, though on a much larger scale, is also comparable.

[2] 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, chaps. xix & xx.

of Dr. Kitchin & Mr. Pringle that the Upper Gault alone is present in sections north of Leighton, and that the irongrit-breccia accompanies this division only, it has been necessary for me during the past year to re-examine as much of the Gault in the neighbourhood as is accessible. The investigation has convinced me that the Lower Gault is continuous over the whole area, and is succeeded conformably by the Upper Gault, but with a long pause in the sedimentation, marked by a band of phosphatic nodules, at or near the base of the Upper Gault.

Leaving controversial points for later discussion (pp. 70, 78), I will briefly review the features of the Lower Gault as exhibited in the sections. Taking the incoming of 'Inoceramus sulcatus' in association with 'Ammonites rostratus' as their upper boundary, the Lower clays (excluding the Mammillatus beds) appear in this neighbourhood rarely to exceed 15 feet in thickness, and may in places diminish to 10 feet, as compared with their 27 or 28 feet at Folkestone. This diminished thickness is maintained for a considerable distance southwards, judging from the description by Jukes-Browne of a boring at Slapton Lock, 3 miles south of Leighton, in which we read[1]:—

'It would appear that there is a nodule-bed about 10 feet from the base of the Gault; among the fossils preserved I identified the following, *Ammonites interruptus*, *Am. cristatus*, *Am. rostratus*, *Am. varicosus (?)*, *Inoceramus sulcatus*, *Inoc. concentricus*, *Inoc. tenuis (?)*'

—a similar assemblage to that which the same investigator collected from the nodule-bed in the Heath brickyard (p. 27), and to that of the equivalent nodule-bed at Harris's pit (p. 7).

This reduction of the Lower Gault as we approach the shelving coast-line of the period has its exact counterpart in the North of France where, at Wissant, its thickness is only 16 feet (with 2 feet of basement Mammillatus beds below, almost exactly as at Shenley) and still less in the country to the east, but expands to over 30 feet in the Argonne region, and to over 100 feet in parts of the departments of Marne, Haute Marne, and Aube; remaining throughout its range, however, always very much thinner than the Upper Gault.[2]

The sections afford a reasonable explanation for the thinness of the Lower Gault in the Leighton district. Everywhere, except on

[1] *Op. supra cit.* Mem. Geol. Surv. p. 279; the authors, however, did not recognize that the Lower Gault was comprised in the clays below the nodule-bed, and thought, with some misgivings, that it must include some higher clay or marl. In their conjectural classification of another boring, at Gubblecote, 6 miles south of Leighton, they allow 145 feet to the Lower Gault; but I suspect that they should have confined it to the 22 feet of 'dark brownish clay, becoming sandy and glauconitic below' which has a 'layer of phosphatic nodules' above it, and has beneath it, 3 feet of 'blue sandy clay with phosphatic nodules at the base' (*ibid.* p. 282).

[2] C. Barrois 'Sur le Gault dans le Bassin de Paris' Ann. Soc. Géol. Nord, vol. ii (1875) pp. 1–61; and 'Terrain Crétacé des Ardennes' *Ibid.* vol. v (1878) pp. 227–487; A. J. Jukes-Browne, 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, chap. xxvii.

the eminences capped by smooth iron-pan, the bottom layers of clay (4 a), for several inches up, are sprinkled with coarse grit and small pebbles ranging up to the size of peas, which denote the continuance of current-action, less forceful indeed than during the accumulation of the underlying Basement bed, but yet strong enough to retard the sedimentation of clayey matter. Consequently these few inches of gritty clay, usually quite unfossiliferous, may represent a time-equivalent as long as, or longer than, that of the 10-ft. '*interruptus*-bed' (Price's I) of Folkestone; and their absence on the knoll-tops may indicate the lapse of the same period without sedimentation. In the overlying gritless clays (4), the presence of strings of undisturbed brown-coated phosphatic nodules is still indicative of slow sedimentation, and the scantiness and crushed condition of the fossils point the same way, as most organic remains require quick burial for their preservation. So far as the scanty fossil-evidence goes, these gritless clays probably represent, more or less imperfectly, Beds II to VI of Price's Folkestone classification; but it is hardly likely that all the Folkestone subdivisions can be separately distinguished in this condensed sequence, just as it has been found impracticable in the similarly-condensed sequence of the North of France. As in France, too, 'Belemnites minimus' is the most abundant fossil of the beds, and is rare or absent in most of the Upper Gault.

Besides this deficiency towards its base, the Lower Gault shows also an arrest of development at its top, which must have had a further effect in reducing its thickness, though at this horizon the Folkestone section has suffered similarly, as Price has impressively shown.[1] The phosphatic nodule-bed exposed near the top of Harris's pit (fig. 3, p. 7), and less clearly in evidence in other sections, has its equivalent, as already shown (p. 9), at approximately the same horizon at Folkestone (Price's Bed VIII, 'the Junction-bed'), where identical conditions are implied. It is likely enough, however, that these conditions were not absolutely synchronous in two spots so far apart, as their belt of impact probably moved from place to place under the influence of the progressive changes. The 'compound' character of the nodules and the way in which many have been abraded, and scarred by adherent organisms, while others are comparatively intact, afford proof of original slow deposition, of subsequent winnowing-away of the matrix, perhaps more than once, and of time for the regrowth of concretionary matter around the old nuclei. We are, in short, dealing with a 'condensed deposit'; and the assemblage of fossils found elsewhere at separate levels, first commented on by Jukes-Browne,[2] is thus to be accounted for. The mixture appears to be somewhat greater than at Folkestone, which may imply either an earlier beginning and longer persistence of the conditions, or the winnowing-away

[1] 'The Gault' *op. supra cit.* p. 9.

[2] 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, pp. 275, 278, 285.

of a greater thickness of clay. The fossils of the nodules include many that are characteristic of the lower part of the Upper Gault; therefore, as at Folkestone, it is a convenient 'Junction-bed' for the subdivisions.

It is particularly to be noted that no extraneous pebbles have been found in this nodule-bed. Indeed, its clay-matrix is not even gritty; and the condition and position of the ammonite-casts mentioned in the earlier part of this paper (footnote, p. 9), together with the very variable size and shape of the nodules, afford further proof that the sea-currents at this stage were too weak to shift any heavy material.

The absence of pebbly matter and of any fragments of iron-grit marks the sharp difference between this bed and the Basement-bed of the Lower Gault. In no part of the district, nor indeed elsewhere in England, so far as I am aware, has any bed resembling the irongrit-breccia been found intercalated between the Upper and the Lower Gault.

The higher part of the Upper Gault requires no discussion in this paper. So far as seen, it is quite different in aspect and fossils from the clays with which I have dealt (see p. 37).

V. Discussion of the 'Overturn' Hypothesis.

I may now, before concluding, enter into a particular consideration of the points of issue raised by Dr. Kitchin & Mr. Pringle, although most of these have, I think, been incidentally met and controverted by the foregoing descriptions. The supposition that the Gault, limestone, and glauconitic sand at Shenley Hill have been inverted by Glacial action is based mainly upon a palæontological argument, to explain the presence of some fossils in the limestone, that were not previously known to occur below the English Gault. The anomalous character of the fossil-assemblage in this respect was duly discussed and, I think, adequately explained in our previous paper; but our explanation has been set aside. In support of their palæontological argument, Dr. Kitchin & Mr. Pringle have brought forward some stratigraphical considerations, which I will deal with first.

The stratigraphical argument.—Some fundamental points telling strongly against the inversion-theory were stated in my letter to the Geological Magazine (May 1920, pp. 234–37), close upon the publication of the hypothesis. The gist of these may be re-stated in brief as follows:—

(1) The absence of any rock resembling the peculiar Shenley limestone, either in composition or in fossils, from any part of the outcrop above the Gault in the Chiltern escarpment, and the entirely different character of the known beds at this horizon.

(2) The unweathered condition of the thin cakes of limestone and of the wedge of loose glauconitic sand, which are supposed to have lain at the surface before being overturned.

(3) The absence of any trace of Drift material along the supposed disruption-plane or in the overlying mass, and the lack of any structural indication of Glacial disturbance in the mass. Also the improbability that a slab of soft Gault clay, greensand, etc., not less than 15 acres in area and 18 feet or more in thickness, could be turned over, pancake-fashion, and dropped back onto a flat bed, without disruption or entanglement with Glacial material.

(4) The presence of a floor of unbroken iron-pan immediately above the limestone, with evidence that it was in the same position before the Gault was deposited (*antea*, p. 63).

To these objections I may now add :—

(5) The absence, so far as is known, of relics of similar limestone in the Boulder Clays of the district.

(6) The presence of similar limestone, containing some similar fossils, in a bed immediately below the Gault at Long Crendon (p. 41); also at Southcott (p. 38) and Littleworth (p. 39).

(7) The extreme improbability, in view of its general arrangement in the region,[1] that the Upper Gault around Shenley Hill was, as required by the inversion-hypothesis, 'little more than 40 feet in thickness' (K.P., p. 108) when the Lower Chalk was deposited.

Next, to consider some points of detail :—

(8) I am unable, for reasons previously stated (p. 55), to accept the statements (I) that the upper part of Silty beds seen at Miletree Farm [and in other pits north of Shenley Hill] is equivalent to the so-called '*tardefurcata* bed' and contains gritty phosphatic nodules similar to those which elsewhere have yielded the Mammillatus-fauna, and (II) that nodules of this kind in the overlying beds have been 'derived' from it. The Silty series is quite different in composition, and was accumulated under different conditions, from the gritty glauconitic loams of Grovebury and Chamberlain Barn in which, as in France also (p. 58), these nodules are always found and are reasonably held to have originated. No palæontological evidence is adduced for the proposed correlation; indeed it is definitely stated—

'We could not break open a sufficient number of the nodules to enable us to obtain any of the characteristic ammonites, although a few other fossils [not specified] were found' (K. P. p. 55).

The unnecessary difficulties raised by the proposed correlation affect the whole account given by Dr. Kitchin & Mr. Pringle of the Miletree-Farm and neighbouring sections.

(9) The palæontological argument for the assumption that the Lower Gault is absent in the Shenley and neighbouring sections is

[1] Borings south of Leighton have proved the full thickness of the Gault to be about 230 to 250 feet, of which probably not more than 20 to 25 feet is Lower Gault (*antea*, footnote, p. 66). See A. J. Jukes-Browne, 'The Gault & Upper Greensand' Mem. Geol. Surv. 1900, pp. 279, 284.

accompanied by arguments based on the lithology, preluded by the general statement—

'It is a matter of surprise to us that this clay [in Harris's pit] has even been mistaken for Lower Gault' (K.P., p. 13).

This, however, merely expresses a personal impression, which is not likely to be shared by anyone who examines all the exposures of the Gault in the district, and notes the very different aspect of the Upper Gault in the undisputed sections farther south (see p. 37). The 'true Lower Gault of the district,' with which the lower clay of Harris's pit is unfavourably compared (K.P., p. 13) on account of 'the absence of sand and the rarity of glauconite,' can only refer to the 4 or 5 feet of gritty clay above the Mammillatus beds in the Grovebury pits, since the clays of all the other sections which they describe are assigned by Dr. Kitchin & Mr. Pringle to the 'Upper Gault.' But this peculiar gritty condition is confined to the lowest bands only of the Lower clays; it is present all round the Shenley reef in the lowest layers of the Gault-filled hollows, as I have shown, and is absent only on the bare top of the reef (p. 67). So far as I can judge, the Lower clays above these gritty layers are alike in all the exposures, with only such insignificant differences as one expects to find in passing from place to place.

In correlating the various sections of supposed 'Upper Gault,' Dr. Kitchin & Mr. Pringle lay great stress upon two lithological peculiarities as proofs of age:—

(i) 'conspicuous small white nodules (white throughout) is a point to be 'specially noted, since, owing to the rarity of fossils, the presence of these 'nodules is helpful in identifying these beds [that is, 'Upper Gault Clay' and 'Basal bed of Upper Gault'] in other sections' (K.P., p. 57); and (ii) 'im 'perfectly bedded, crumbled, grey clay . . . . of a peculiar type . . . . made up 'of innumerable small pellets, which are for the most part somewhat angular 'in shape. It might be termed a finely brecciated clay' (K.P., p. 58).

So far as I can discover, the 'small white calcareous nodules' (i) referred to are the knots of 'race,' produced by recent weathering and segregation of lime where the calcareous clays approach the surface. This 'race' is exhibited in varying quantity, usually at a depth of 2 to 5 feet, in the top clay of most of the Gault sections, without relation to the stratigraphical horizon; it was plentiful in the clay just above the Mammillatus bed in Pratt's pit at Grovebury (p. 35), occurring also in other sections at this level (p. 30); it is most abundant where the beds have been affected by 'creep.'

The 'brecciated clay' (ii) appears to be the superficially disturbed clay ($\frac{ZY}{4}$ of my sections) seen above the bedded Gault in most places where the clay-deposits come to the surface. This structure is the normal result of 'surface-creep' or 'trail' in breaking up and incorporating soft beds in the lower part of the 'creep'; wherefore its supposed origin as 'the redeposited débris resulting from the denudation of some previously formed, well-

consolidated clay' (K.P., p. 58) may in one sense be allowed, but not in the sense implied by the authors, who consider that the structure is original and indicative of a definite horizon in the Gault. In such shallow sections as those in which the 'race' and the brecciated structure are seen, one could hardly expect to find soft calcareous clays of the Gault type in their original condition, particularly on sloping ground.

The interpretation of the thin continuous band of Basement beds around Shenley as being 'a remarkable collocation of heterochronous elements' (K.P., p. 12), composed in part of post-Glacial iron-grit, in part of Glacial gravel, in part of Cenomanian limestone, in part of Upper Greensand, and in part of an Upper Gault Basement bed containing derivative Lower Greensand fossils, is so entirely dependent upon the palæontological argument that it requires further consideration only from the palæontological standpoint, which I shall now attempt.

The palæontological argument.—As bearing on the general aspect of the fossil-evidence, we may recall that this is at least the third time in English geology that fossiliferous beds occurring below the Gault have been held, on palæontological grounds, to be newer than the Gault. First, the Faringdon Sponge-Gravels, notwithstanding previous opinion, now accepted, were supposed by T. Davidson,[1] on the evidence of their brachiopoda, to be possibly of Upper Greensand age; and by D. Sharpe,[2] because of their polyzoa, to be newer even than the English Chalk, and probably 'Danian.' Particular stress was laid by both authors on comparisons with the Tourtias of the Continent; but, as Caleb Evans[3] pointed out, the argument might be legitimately reversed by questioning the reputed age of the Tourtias—themselves of uncertain antecedents.

Again, some 30 years later, the presence of the Gault in part of West Norfolk was challenged by C. Reid & G. Sharman,[4] who argued that the calcareous clay in question was the Chalk Marl, mainly on the ground that—

'not a single characteristic Gault form occurred, but that there were several species which have not been recorded from below the Lower Chalk,'—

the unquestionable Gault species in a phosphatic-nodule bed at the base of the clay being all regarded as 'derivative.' The challenge was answered effectively by A. J. Jukes-Browne & W. Hill,[5] who

[1] 'Monogr. Brit. Cret. Brachiopoda' pt. ii, p. 3, Pal. Soc. 1852.

[2] 'On the Age of the Fossiliferous Sands & Gravels of Faringdon & its Neighbourhood' Q. J. G. S. vol. x (1854) pp. 176–98.

[3] 'Sketch of the Geology of Farringdon' Geol. & Nat. Hist. Repertory, containing Proc. Geol. Assoc. No. 16, Aug. 1866, pp. 33–40.

[4] 'On the so-called "Gault" of West Dereham, in Norfolk' Geol. Mag. 1886, pp. 55–59.

[5] 'Note on the Gault & Chalk Marl of West Norfolk' Geol. Mag. 1886, pp. 72–74; and 'On the Lower Part of the Upper Cretaceous Series in West Suffolk & Norfolk' Q. J. G. S. vol. xliii (1887) pp. 547–49 & 571–74.

showed that the Gault forms were proper to the bed and that the clay was stratigraphically distinct from the Chalk Marl. The bearing of this discussion on the present case is close, not only by reason of the stratigraphical horizons involved, but also because most of the fossils dealt with in the argument are species found at Shenley, and now again brought into question: such as—'Inoceramus concentricus' with 'crippsi' and allies, 'Ostrea vesicularis,' 'Belemnites minimus' and vars., etc.

The limestone fauna.—The argument for the 'Cenomanian' age of the limestone is not based on a consideration of the fauna as a whole, but on certain species the occurrence of which is supposed to be impossible below the Gault; other species, to be regarded as neutral, are not discussed; and those which tell distinctly against the hypothesis, if mentioned at all, are considered 'without doubt' to be derivative. I think that it will bring the matter into better perspective if I summarize the evidence in each Class, and add particular comments on the species which have been used in the argument as they come under review.

Cephalopoda.—Of the ammonites (six specimens in all), those recognizable belong to two forms proper to the Mammillatus Zone and not known to occur above it. The evidence against the supposed derivative origin of the identified specimens has been already stated (p. 47). The belemnites (two specimens) are probably a form of *Neohibolites* occurring in the same zone (p. 47).

Gastropoda (see p. 47).—No specific identifications have been made, and no argument raised. The assemblage will probably be found to present a 'Lower Gault' facies, and to have its equivalents among the rich fauna of this Class recorded from the Mammillatus Beds of Northern France.[1] If there had been any recognizable 'Cenomanian' forms among them, I think that they would have been mentioned in the discussion.

Lamellibranchiata (see p. 47).—Only four species received positive determination in our original list (L.W., p. 263), and all are species known to range downwards in the Lower Greensand, at least as low as the Hythe Beds, and upwards into the Chalk. They happen to embrace the commonest fossils of their Class in the limestone. Of the six more or less doubtful determinations in our original list, three were species not previously known above the Lower Greensand, and the other three were known only in or above the Gault. One of the latter, *Lima globosa*, has since become a positive determination, and will be further commented on.

Of the five or six new determinations (pp. 57–58), *Inoceramus concentricus* is important in strengthening the relationship of the bed with the overlying clays; while *Pteria pectinata*, an abundant fossil at Shenley, has a wide distribution, ranging from the Hythe Beds up into the Chalk, but is commonest in the Lower Greensand.[2] These two species are not referred to by Dr. Kitchin & Mr. Pringle, who quote the four following in support of their argument:—

(i) *Pecten curvatus*, 'which occurs in the Upper Greensand of Great Haldon and in the Chloritic Marl' (K.P., p. 5). Regarding this small pecten, Mr. H.

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[1] See list in C. Barrois, 'Terrain Crétacé des Ardennes,' Ann. Soc. Géol. Nord, vol. v (1878), pp. 269–75.

[2] H. Woods, 'Monogr. Cretac. Lamellibr.' vol. ii, pt. 2, p. 59, Pal. Soc. 1905.

Woods notes[1] that the species, for which English material is scanty, 'closely resembles *P. striato-punctatus* Römer,' a shell of wide range in the Lower Cretaceous and doubtfully present in the Gault of Folkestone, where it is recorded by Price as occurring in the 'Junction Bed' VIII.[2] The Shenley shell may be found to correspond to the Gault form.

(ii) *Cyprimeria rotomagensis*, 'a species of the basal Cenomanian of Wiltshire' (K.P., p. 5), is, I believe, a somewhat doubtful determination. It is, at the best, a rather featureless shell, and is usually preserved as casts. The genus has two species in the Lower Greensand of the Isle of Wight, one of which, *C. parva*, is near to this form. The known range of the genus in the English Cretaceous rocks is from the Atherfield Beds to the Lower Chalk.[3]

(iii) *Isoarca obesa*, 'which is not known elsewhere from below the Chloritic Marl' (K.P., p. 5). This species is regarded as synonymous with *Isocardia orbignyana* A. d'Archiac, occurring in the Flemish Tourtias.[4] A. J. Jukes-Browne, in his General List of Chalk Fossils,[5] marks it as 'found in Selbornian,' but does not include it in the 'Selbornian' List in his previous volume,[6] where the only species mentioned is *Isoarca agassizi* P. & R. Presuming that the identification is unquestionable, the presence of the species at Shenley increases its hitherto known range.

(iv) *Lima globosa*. Since the downward range of this fossil through the Gault is admitted, it seems beside the mark to note that 'the type . . . . came from the Chloritic Marl' (K.P., p. 6). The Lower Chalk is the limit of its upward range. The species is recorded by Price[7] from near the bottom of the Lower Gault (Bed II) at Folkestone. Mr. Woods[8] remarks that it 'closely resembles *Lima albensis* d'Orbigny,' a species mentioned by Prof. C. Barrois[9] as occurring in the Mammillatus Beds as well as in the Lower Gault of the North of France. There is nothing incongruous in the presence of *Lima globosa* in the Shenley limestone.

Dr. Kitchin & Mr. Pringle bring also into the argument two species of small oyster, which I found in the wedge of greensand in Garside's pit (pp. 10–12), believed by them to be inverted 'Upper Greensand.' They mention them as 'well-developed valves of *Ostrea vesicularis* Lamarck, such as are 'found in the zone of *Pecten asper* Lamarck; also *Ostrea canaliculata* (J. 'Sowerby), a species which occurs much more commonly above the Gault than 'below it' (K.P., p. 6). But both species, believed by Woods to be allied,[10] begin their long range in the Lower Greensand, *O. canaliculata* being found as low as the Hythe Beds, so that their presence below the Gault, whenever conditions favoured their growth, might be anticipated and certainly needs no abstruse explanation.

On the other hand, the absence, so far as known, of the commonest oysters of the Upper Greensand, *O. vesiculosa* and *Exogyra conica*, is awkward to explain on the overturn-hypothesis.

As for the limestone, if it were 'Cenomanian,' we ought to find in it some of the commoner lamellibranchs of the period; as, for example, *Pecten asper*, *P. beaveri*, *Lima aspera*, *L. elongata*, *Pholadomya decussata*, etc.; all, as yet, missing.

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1 *Ibid.* vol. i. pt. 4, p. 161 (1902).

2 'The Gault' p. 56.

3 H. Woods, *op. cit.* vol. ii, pt. 9 (1913), Tables, pp. 439, 447.

4 *Ibid.* vol. i, pt. 1 (1899) p. 65.

5 'The Cretaceous Rocks: vol. iii—The Upper Chalk' Mem. Geol. Surv. 1904, p. 477.

6 'The Cretaceous Rocks: vol. i—The Gault, &c.' Mem. Geol. Surv. 1900, p. 467.

7 'The Gault' p. 54.

8 *Op. supra cit.* vol. ii, pt. 1 (1904) p. 17.

9 'Terrain Crétacé des Ardennes' Ann. Soc. Géol. Nord, vol. v (1878) p. 274.

10 *Op. supra cit.* vol. ii, pt. 9 (1913) pp. 360–78.

Brachiopoda.—Respecting this Class, it is first necessary for me to take exception to an implication by Dr. Kitchin & Mr. Pringle that the late J. F. Walker was swayed by stratigraphical considerations in naming these fossils. Their statement is—'They [that is, Lamplugh & Walker] met the 'difficulty by explanations which we have always considered to be inadequate, 'while they treated as so-called "varieties" some of the species which appeared 'to occur so far below their usual horizon. Arguing from stratigraphical 'inferences, they claimed to demonstrate that these species in reality made a 'much earlier appearance and possessed a much longer vertical range than had 'previously been suspected. We need make no lengthy comment here on this 'manner of dealing with the palæontological aspects of the bed,' etc. (K.P., p. 5.)

But Walker's attitude throughout, in working on the brachiopoda, was the reverse of that imputed to him. He recognized from the first that these fossils had their nearest analogues in those of the Tourtias, and he was ready to stretch the comparison to bring them within the limits of established species (L.W., p. 247). His previously quoted letter (p. 46) is sufficiently explicit in this matter, and others of his to me have the same tenour; as, for instance, 'The *Zeilleria* are very difficult. I don't want to make new species unless obliged' (letter, December 28th, 1902), and 'I fear we shall have to make a new species of the *Terebrirostra*' (October 13th, 1902, and a similar phrase with regard to the same form in a later letter).

I know that especial importance has been assigned to the last-mentioned fossil, eventually described and figured by Walker as *Terebrirostra lyra* (Sowerby) var. *incurvirostrum* nobis, and I will therefore discuss it further in this connexion. *T. lyra* had long been prized as a rare and curious fossil both in this country and abroad, and the discovery of a shell of this type in unexpected abundance, along with another rarity, *Terebratula capillata*, in even greater abundance, in the Shenley limestone, provoked Walker's immediate interest, and induced him to enter vigorously into the investigation of the bed. Apparently *Terebrirostra* had never before been represented by such richness of material from one place, exhibiting manifold growth- and varietal-phases, and this rendered comparison with the previous scanty material more difficult. There is a species, *Terebratula arduennensis* d'Orbigny, closely resembling *lyra*, occurring in the Mammillatus Beds of the Ardennes [1] and in some of the Tourtias,[2] respecting which Walker wrote to me (January 16th, 1903): 'I want a *Terebrirostra arduennensis* to compare with ours. I have written to [a foreign correspondent]; he is trying to get me one.' But, apparently, the attempt was unsuccessful, as no example of the species is to be found in Walker's rich collection of foreign brachiopoda now in the Natural History Museum; and the critical comparison, much to be desired, is probably still lacking.

It is, at any rate, certain that a *Terebrirostra* near to the Shenley and Long Crendon fossil has its horizon in the Basement-beds of the Gault in France; and among the five species of this aberrant genus recognized by A. d'Orbigny, one occurs in still older beds, namely, *T. neocomiensis* d'Orbigny, found in the Lower Cretaceous.[2] Consequently, there is nothing astonishing in the appearance of the fossil where we have now found it.

The following analysis will serve to show the general aspect of the brachiopod-fauna of the limestone.

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[1] C. Barrois, 'Terrain Crétacé des Ardennes' *op. cit.* p. 275.

[2] 'Note sur . . . . *Terebrirostra*, &c.' Journ. Conchyliol. vol. ii (1851) p. 222. *T. neocomiensis* is figured by Zittel to illustrate the genus, in 'Text-Book of Palæontology' Eng. transl. London, vol. i (1900) p. 331. Another of A. d'Orbigny's five species, *T. canaliculata*, is from the Tourtia; but Davidson considers that this form is a true *Terebratella*, and not a *Terebrirostra*: see 'Monogr. Brit. Cret. Brachiopoda' Pal. Soc. pt. ii (1852), footnote on p. 32.

Of the 28 species and varieties named in our previous paper (L.W., p. 262):—

5 had been found previously in England only in the Lower Greensand; but two of these are recorded from Continental Tourtias, and other two from the Mammillatus Beds of Northern France.
2 had been found as rare fossils in Lower Greensand and also in the lower part of the Upper Cretaceous of England. Both are Tourtia shells. One of them, *Terebratula capillata*, is the commonest fossil of the limestone.
8 (or, including *Terebrirostra lyra* var., 9) had been found only above the Lower Greensand, four occurring in the Gault or Red Chalk and the remaining at higher horizons only. But one or two of the eight are now recognized as occurring in the Upper Aptian of the South of France.[1] The Tourtias are known to contain six of the eight.
4 were new to England, but were previously known in one or other of the Tourtias.
9 were described as new species or varieties.
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28
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In their argument Dr. Kitchin & Mr. Pringle mention five of the species by name (K.P., p. 4), but do not refer, except in general terms, to the other 23.

Among the eighteen or twenty provisional determinations, in addition to the above, resulting from Walker's later work (*antea*, p. 45), not more than two or three are species known in this country; but nearly all are Tourtia forms.

So far from this, the most abundant and most closely studied element of the fauna, requiring the idea of an overturn, it appears to afford actual disproof of the hypothesis.

Correlation with the Tourtias is useless for any narrow and critical demarcation of age, since the Tourtias are known to occur at different horizons where actually intercalated in the Cretaceous sequence; and, where they form the base of that sequence and rest directly on the much older rocks, they are 'condensed' deposits, probably covering a long period, and they then generally contain many fossils not known to occur in beds which lie above the Gault where it is actually present.

The absence from Shenley of the common species of the Upper Greensand and Lower Chalk has already been commented on (p. 45).

The hypothesis of the intermingling of two limestones of different horizons, one presumed to contain, besides its own fossils, others derivative from the Lower Greensand, raises many real difficulties in the place of an imaginary one; and has no basis, so far as the brachiopods are concerned.

Terebratula capillata deserves a further word, as its history is typical of that of several of the commoner brachiopods of the limestone. The form occurs as a rarity in the Lower Greensand of Upware and in the Red Chalk. It is plentiful in several of the Tourtias, and is found also in the French Mammillatus Beds. Its profusion at Shenley, where it is 'in full evolution,' exhibiting a very wide range of varieties (L.W., p. 249), led Walker to propose that we should distinguish the limestone as 'the Zone of *Terebratula capillata*,' which he regarded as the characteristic fossil of the bed (L.W., p. 250). The shifting sand-banks of the Lower Cretaceous strait afforded no opportunity for the establishment or preservation of a 'reef-facies' in the locality

[1] W. Kilian, 'Lethæa Geognostica: II, Das Mesozoicum' vol. iii, 1913. The species are *Terebratula dutempleana* d'Orbigny (p. 306), and (somewhat doubtful) *Rhynchonella grasiana* d'Orbigny (pp. 309, 361). Another species mentioned is *Rhynchonella lineolata* Phillips (pp. 307, 361), but this was already known as a Lower Cretaceous form in England.

until the ferruginous induration of the Shenley shoal provided a suitable habitat. This was soon occupied in force by *T. capillata* and its congeners; and they throve there until the oncoming of the Gault clay-conditions, which put an end to them in this place. The Gault is notoriously poor in brachiopods, particularly the Lower Gault clays, which usually contain none. This species and the *Terebrirostra*, among others, evidently reached their acme at about the beginning of the Gault period, although they lingered for some time longer before extinction.

ECHINODERMATA (p. 48).—The list of the Shenley fossils of this Class is suggestive of a horizon above the Gault, but the anomaly is not so tangible in reality as in print. The only material, except a few spines and other fragments in my own collection, is the Walker collection at Cambridge, containing about a score of ill-preserved tests and some spines, which are acknowledged to be generally too poor for confident determination,[1] and where confidence can be expressed, it is based on one, two, or at the most three, specimens. Our original list (L.W., p. 263) comprised four positive specific identifications; one of these has been reduced by a ? and another by an *aff.* as the result of the recent expert re-examination. Without venturing to question the authoritative determinations, I will submit some comments on the species, which appear to be pertinent.

The echinoid fauna of the Gault clays is scanty, and of a different facies from the shallow rock-reef fauna of Shenley. The English deposits, therefore, have hitherto provided us with little or no information as to the ancestry and progress of the echinoid 'reef-facies' during and just before the period of the clay-sediments. The Tourtias of the Continent, however, contain many relics of this facies; and it is in them, and not in the English beds above the Gault, that comparisons with the Shenley forms should be sought and may, I think, be found.

Catopygus columbarius (a single specimen), one of the smaller echinoderms, is (I believe) regarded as of prime consequence in the argument for the post-Gault age of the limestone. In the West of England it is a well-known fossil of the top beds of the Upper Greensand and the lowest part of the Lower Chalk; but a very similar fossil occurs in the Lower Greensand, and is recorded as *C. carinatus* Goldfuss (supposed to be a synonym of *C. columbarius*) from the Hythe Beds of Hythe.[2] *C. carinatus* is also recorded from the lowest zone of the Albian of the South of France, from beds which we should class as Lower Greensand.[3] *C. columbarius* is a common fossil in some of the Tourtias,[4] and a form near to it is recorded from the 'Sables Verts de Dennebroecq' occurring in association with *Ammonites tardefurcatus* and other fossils of the Mammillatus Beds.[5] The type, if not the actual species, appears, therefore, to have been in existence before the period of the Gault clays.

Nucleolites lacunosus Goldfuss (1 specimen), another small echinoderm, 'one

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[1] H. L. Hawkins, 'Note on a Collection of Echinoids from the Limestone-Lenticles in the Sand-Pits of Shenley Hill' Geol. Mag. 1921, pp. 57–60.

[2] 'Geology of the Weald' Mem. Geol. Surv. 1875, p. 413.

[3] C. Jacob, 'Etudes, &c. sur la Partie Moyenne des Terrains Crétacés, &c.' (*op. cit. antea*, p. 49).

[4] A. d'Archiac, 'Sur les Fossiles du Tourtia' Mém. Soc. Géol. France, ser. 2, vol. ii (1874) pl. xiii, and G. Cotteau, 'Note sur les Échinides Crétacés de la Province du Hainault' Bull. Soc. Géol. France, ser. 3, vol. ii (1874) p. 652.

[5] H. Parent, 'Sur l'Existence du Gault, &c.' Ann. Soc. Géol. Nord, vol. xxi (1893) p. 218. The fossil is recorded as '*Catopygus* cf. *cylindricus* Desor,' with an appended note by M. Lambert: 'Cette espèce se rapproche surtout des *C. carinatus* Agassiz du Cénomanien et *C. cylindricus* Desor de l'Albien,' &c. A. J. Jukes-Browne in his 'Gault' memoir (*op. supra cit.* p. 477) places *C. carinatus* as synonymous with *C. columbarius*. *C. cylindricus* is a characteristic echinoderm of the Upper Aptian of the South of France (see W. Kilian, *op. supra cit.* pp. 309, 362).

of the few confident identifications' (Hawkins), appears to have been found previously in England only in and just above the Upper Greensand; and *Echinospatagus* aff. *murchisonianus* (Mantell) (1 specimen) in the Upper Greensand only. Both genera have many representatives in the Lower Cretaceous.

Cardiaster ? latissimus Agassiz (1 specimen) and *C.* cf. *fossarius* (Benett) (2 specimens) are the largest urchins that have been found at Shenley, measuring $1\frac{1}{2}$ to 2 inches in diameter. Prof. Hawkins states that his suggested identifications are 'given without any real confidence.' The first-named species is a rarity in the Upper Greensand; the second-named is one of its commonest fossils; but in North-Eastern France *Holaster* (= *Cardiaster*) *latissimus* is recorded by Jules Lambert as occurring occasionally in the upper part of the Aptian (of Grandpré) and more generally in the Gault;[1] and in the South of France it is recognized by Kilian (*op. cit.* pp. 309, 362) as an Aptian species. With respect to the Shenley forms, it is of importance to note that an echinoid of similar type occurs in the undoubted Mammillatus-beds at Grovebury. I collected there, from a gritty phosphatic nodule, an imperfect cast (see p. 50), and another specimen of the same kind was obtained by the Geological Survey; Prof. Hawkins refers my specimen doubtfully to *C.* aff. *latissimus* Agassiz (*op. cit.* p. 57) and notes that the Survey specimen, though not specifically determinable, agrees exactly with mine in form and matrix (*op. cit.* p. 60). From the same nodules I obtained the casts of *Pseudodiadema* comparable with one of the unidentifiable limestone fossils (*op. cit.* p. 57).

Pyrina cf. *inflata* d'Orbigny (1 specimen); *P.* cf. *desmoulinsi* d'Archiac (2 specimens); *P.* aff. *lævis* Agassiz (3 specimens). These small urchins may, according to Prof. Hawkins (*antea*, p. 48), be shape-variants of a single species; which presumably is the same as the *P. desmoulinsi* of some of the Tourtias. The genus as at present defined is fully represented in the Lower Cretaceous, so that its appearance under suitable conditions at the base of the Gault is not anomalous. It may be noted that *Pyrina cylindrica* A. de Grossouvre is recorded by C. Jacob (*op. cit.* p. 309) from the lowermost beds of the Albian of Southern France.

Cidaris bowerbanki Forbes, is based, not on a test, but on three spines, and the determination can hardly be reckoned conclusive.

Conulopyrina anomala Hawkins, being a new genus and species (Geol. Mag. 1921, p. 420) has no present value for correlation.

There is nothing among these echinoderms that seems to justify violent stratigraphical methods of explanation. The collection being poor, negative evidence has less weight here than in the case of the brachiopods; but the absence of most of the commoner Upper Greensand and Lower Chalk species would be remarkable if the limestone were really newer than the Gault.

The CRUSTACEAN *Cyphonotus incertus* Bell, mentioned by Dr. Kitchin & Mr. Pringle, represents a comparatively rare type of fossil, respecting which it must be unsafe to draw deductions from the scanty and imperfect material at present available.

In arguing for the Upper Greensand age of the glauconitic sand of Garside's pit, the same writers mention *Serpula antiquata* J. de C. Sowerby as 'a common fossil in the *Pecten-asper* zone of Wiltshire' (K.P., p. 6), but do not mention that it is also a fossil of the Lower Greensand and Red Chalk.[2] They also refer at some length to cirripede-remains from the same bed which were submitted to Mr. T. H. Withers, who 'believes that the more advanced

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1 'Recherches sur les Échinides de l'Aptien de Grandpré' Bull. Soc. Géol. France, ser. 3, vol. xx (1892) p. 89.

2 'Geology of the Weald' Mem. Geol. Surv. 1875, p. 13; 'Gault & Upper Greensand' *ibid.* 1900, p. 476; and T. Wiltshire, 'The Red Chalk of England' Geol. Assoc. 1859, p. 15 & fig.

evolutionary character shown by the valves from Shenley Hill indicate a later geological age' [than the Gault]. The two species identified have a long range in the Gault, as well as later; and there may well be in this case some misapprehension of the supposed evolutionary characters.

The Gault fauna.—The palæontological argument about the Gault centres around two points:—

(i) The supposed inversion of the clays under Shenley Hill; and (ii) the supposed overlap of the Lower by the Upper Gault in other sections.

On both points the evidence brought forward by Dr. Kitchin & Mr. Pringle in their paper is singularly weak.

(i) To support their statement that the dark lower clays of the Harris's-pit section (fig. 3) are newer than the overlying pale clays, they depend upon three fossils of the lower beds (K.P., p. 13):—an *Inoceramus* 'suggestive of *I. crippsi*'; 'small impressions of the characteristically ornamented *Nautilus deslongchampsianus* d'Orbigny'; and the compressed ammonite of the 'auritus'-stock identified as *Hoplites catillus* (see *antea*, pp. 51–52).

The *Inoceramus* I have already discussed; it is not the form defined as *I. crippsi* by Mr. H. Woods in his recent monograph,[1] although it has sometimes carried that name, but is a form common in the lower part of the Gault (*antea*, p. 51). The *Nautilus* may or may not be correctly identified; it is a small crushed impression, without shape, and hardly comparable with the figured type; and the species has not (so far as I am aware) been previously recorded from any part of the Gault clays in England.

The weight of the argument has apparently to rest mainly upon the crushed ammonite, and it is unfortunate that the species should be one of considerable difficulty. It is discussed at some length by E. T. Newton & A. J. Jukes-Browne in the 'Palæontological Appendix' to the 'Gault & Upper Greensand' memoir (*op. cit.* pp. 443–45), who note, among other points, that 'the flatness exhibited by so many specimens is evidently in most cases due to compression after embedment, and is not an original character.' Jukes-Browne confined his determination to a form occurring in the Upper Greensand, and did not recognize the species as occurring in the Gault clays (*op. cit.* p. 458). Dr. Kitchin & Mr. Pringle identify their crushed Shenley specimens with the Upper Greensand form, and conclude that 'they are members of an easily recognizable hoplitid group which have reached an evolutionary stage characterized by degeneration of the sculptural features.' But the characters requisite in the specific determination are precisely those most likely to be simulated in specimens compressed to the condition of 'films on the bedding-surfaces,' as the Shenley examples are. The questionable Shenley ammonite belongs to a sub-genus ranging

[1] 'Monogr. Brit. Cretaceous Lamellibranchia' vol. ii, pt. 7, pp. 273–78, Pal. Soc. 1911.

through the Lower and most of the Upper Gault, and it occurs where we should normally expect to find something of this type on the analogy of the Folkestone section, in which Price notes ('The Gault,' *op. cit.* p. 15) that his 'Bed II' contains 'a variety of *Am. auritus*, having long tubercles, which may perhaps be a distinct species.' My tuberculate specimen crushed in the vertical plane (see p. 52), poor as it is, could not be called 'catillus,' and indicates the presence of an undegenerate Hoplitid in the anticipated position. The determination of the *catillus*-species on such material must be open to doubt; and, whatever it may be, the fossil is not strong enough to bear the strain put upon it.

In the foregoing notes I believe that I have dealt with every species relied upon by Dr. Kitchin & Mr. Pringle in their argument. It only remains to be pointed out that the preceding descriptions have shown that the lower clays at Shenley Hill contain the usual abundance of 'Belemnites minimus' and crushed 'Inoceramus' which characterizes the lowest part of the Gault clays all through this region; and that they have yielded none of the undoubted Upper Gault fossils which occur so plentifully in the overlying band of pale clay with phosphate-nodules.

I conclude that the Shenley clays are not inverted, but in normal sequence.

(ii) On the second point there is little more to be said than has been already implied. The fact that Lower Gault fossils were formerly obtained from the Heath House sections (p. 27) practically answers the whole of the argument. Having assumed that the Lower Gault was absent there, Dr. Kitchin & Mr. Pringle throughout their paper have been led to apply the term 'Upper Gault' not only to this section but to all the lowest clays of the sections around Shenley. The only reasons stated, so far as I can find, are :—

> 'We infer that the Gault *in situ* at Shenley Hill was originally some 40 feet 'thick at the most; and we consider that the presence of the fauna of Bed IX 'of Folkestone such a short distance up in the series makes it certain that 'only the Upper Gault is represented here' (K.P., p. 60) —[an argument with which I have already dealt, *antea*, p. 66; and, referring to the Miletree-Farm section] :—'We have nowhere seen any exclusively Lower Gault fossil in it' (K.P., p. 57).

But the latter statement requires to be amplified by the addition of 'nor any exclusively Upper Gault fossil,' since it is mentioned that only *Belemnites minimus* was seen in the clay of this section, and only the same fossil and *Inoceramus concentricus* in the remaining pit (Garside's) in which the 'Upper Gault overlap' is postulated.

It is true that our knowledge of the full Gault sequence in Bedfordshire and Buckinghamshire is still very imperfect; but I think that it has been confused, and not advanced, by the proposed new interpretation of the Shenley sections.

VI. Summary.

The paper, a continuation of one by the Author and the late J. F. Walker published by the Society in 1903, describes about twenty sections exhibiting the base of the Gault in sandpits and other excavations around Leighton Buzzard and westwards at Southcott, Littleworth, and Long Crendon.

(1) The variable 'Basement beds' of the Gault are 'condensed' deposits, strongly influenced by local conditions like the 'Tourtias' of Flanders, and falling mainly within the 'zone of Ammonites mammillatus' as recognized in Northern France (= zones of A. regularis and A. tardefurcatus of a later German classification).

(2) The evidence bears out Jukes-Browne's suggestion of the occurrence of a current-swept strait in this quarter during late Lower Cretaceous times, uniting northern and southern sea-basins. During the accumulation of the 'Basement beds,' a shoal in this strait north of Leighton formed a reef capped by ferruginous 'pan' and breccia, with lenticular patches of shell-limestone preserving a fauna of 'reef-facies,' while the deeper water to the south gathered a stratum of gritty glauconitic loam and clay with fossiliferous phosphatic nodules of the French 'coquins de sable' type. The transitional stages are visible in the sections.

(3) The dark clays above the 'Basement beds' belong to the Lower Gault, here reduced to about half its thickness at Folkestone, the same reduction being exhibited also towards the opposite edge of the basin, in Northern France. These clays rest sharply on the ironstone 'pans' of the reef, but usually pass downwards by gritty intercalations into the glauconitic loams. Fossils other than 'Belemnites minimus' and 'Inoceramus concentricus' are scarce and in a poor state, but are in agreement with the stratigraphical evidence.

(4) The incoming of the Upper Gault, with keeled ammonites of the 'rostratus' group and 'Inoceramus sulcatus,' is indicated in three of the sections, of which, however, two are at present obscure. A band of corroded phosphatic nodules, like those of the 'Junction-Bed' at Folkestone, occurs near the base of the division, and marks a pause in the sedimentation. This band has yielded many fossils.

(5) The palæontology of the deposits is discussed, and is held to be in general agreement with that of the same succession in Northern France.

(6) A recent suggestion that the beds at Shenley Hill may have been inverted by Glacial agency is fully considered, and shown to be untenable.

[**March 31st, 1922.**]

Discussion.

Prof. H. L. Hawkins, speaking as an unrepentant palæontologist, congratulated the Author on the lucid and almost convincing expression of his views. From a careful study of the Echinoid fauna of the 'limestone lenticles,' the speaker had come to the conclusion that a Cenomanian facies was definitely indicated; and this was the opinion of the majority of specialists who had examined other groups of fossils from those deposits. His view was that, had stratigraphers chanced to agree as to the Cenomanian age of the masses in question, no further interest (of a horizonal nature) would have attached to the fossils. As matters stood at present, there seemed to be a clear issue between stratigraphy and palæontology: to put back the time of appearance of a single species would be justifiable, but to treat practically an entire fauna in such a manner vitiated the principle of 'time-indication' by the evidence of fossils. Hence he hesitated to accept the Author's conclusions, although, apart from the palæontological evidence, they appeared reasonable and even obvious.

Mr. J. Pringle regretted that no new facts had been brought forward, and said that he would like to defer his criticism until the paper was published. He would remark, however, that he thought that the interpretation put forward by Dr. F. L. Kitchin and himself was the correct interpretation of the facts.

The Author, in reply, said that he had expected that the critics of the previous work of himself and the late J. F. Walker would have embraced the opportunity to support their strictures. Since they had not done so, there was little scope for discussion.

The palæontological argument for the supposed inversion was out of perspective, through his critics having insisted on particular species and on their upward range, without having mentioned also their downward range and the presence of other species not favourable to their views. The echinoderms had been dealt with, along with all the other fossils brought into the argument, in a portion of the paper which there had not been time to read.

No palæontologist could suppose that his material, however plentiful, represented the final limits of our knowledge; and he must occasionally have to meet facts novel to his experience. Purely palæontological methods of explaining the facts regarding the fossils were available, and could be applied, without recourse to an indefensible Glacial overturn.

2. *The* Structure *of the* South-West Highlands *of* Scotland.

By Edward Battersby Bailey, M.C., B.A., F.R.S.E., F.G.S. (Read March 23rd, 1921.)

[Plate I—Geological Map.]

Contents.

I. Introduction.

The gradual development of structural interpretation in regard to the South-West Highlands of Scotland has much in common with the long-continued building of some great cathedral. The workers have been many, each with his own individuality, and each influenced by the spirit of his time. In these circumstances,

preparatory demolition has been an almost inevitable feature of every attempt at improvement. But one is emboldened to the task by the thought that restoration can be carried out if occasion proves its need: a fairly representative literature enshrines the observations and opinions of the long line of researchers.[1]

Statement of the Problem.

As a preliminary to discussion, the following dogmatic statement is offered. The schists of the South-West Highlands of Scotland belong to three main structural divisions, which, in descending order, are (fig. 1, p. 84 & Pl. I):—

Loch-Awe Nappe,
Iltay Nappe,
Ballappel Foundation.

The first title is derived from Loch Awe. The second is a hybrid of Islay and Loch Tay. The third is compounded from Ballachulish, Appin, and Loch Eilde.

Each great division has its particular stratigraphical facies, although there are certain correspondences which suggest stratigraphical correlations from one to another.

The Loch-Awe Nappe is relatively simple in structure. The Iltay Nappe includes two important recumbent folds—the Ben-Lui Fold, a syncline closing towards the north-west, and the Carrick-Castle Fold, an anticline closing towards the south-east (fig. 4, p. 102 & Pl. I). The Ballappel Foundation is a structural complex, with the Ballachulish and Appin Nappes among its component parts. During the development of these various structures, movement took place persistently towards the south-east.

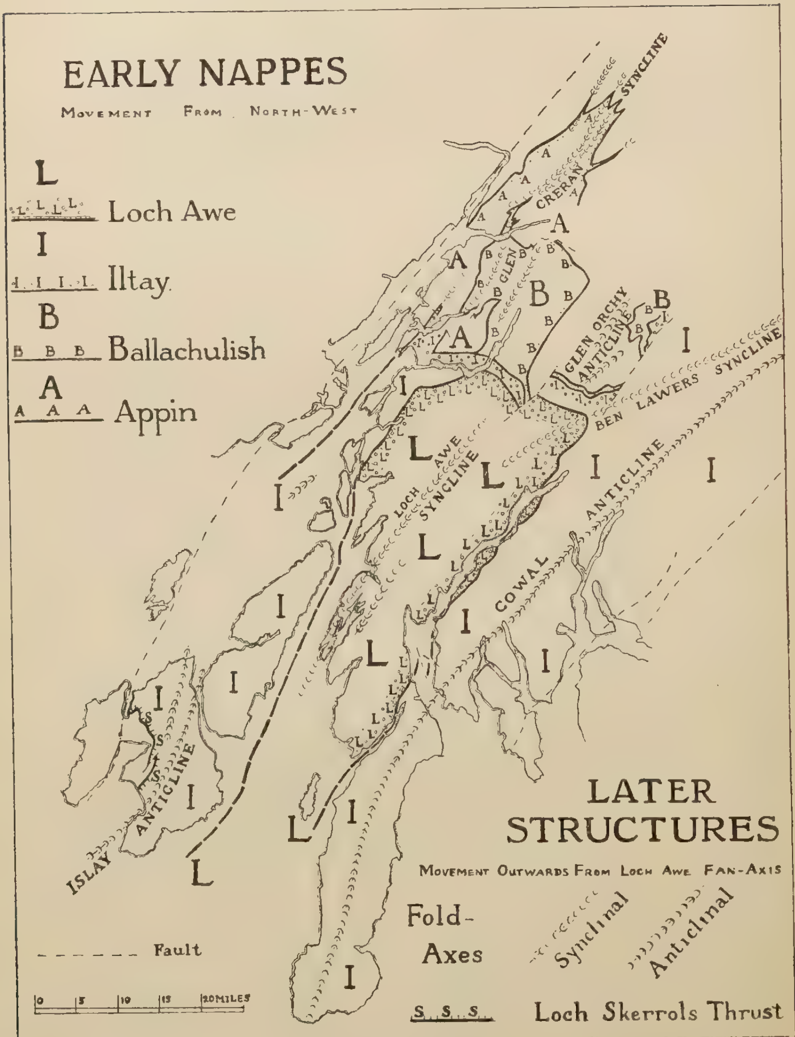
Little would be known of all the nappes and recumbent folds just mentioned, were they not bent and buckled by what we may term secondary folding. The secondary folds of the South-West Highlands are picked out in fig. 1. They include such conspicuous examples as the Cowal Anticline, Loch-Awe Syncline, Islay Anticline, etc. In regard to a large part of the region, it may be stated that the secondary movements were directed outwards in both directions from the axis of the Loch-Awe Syncline. The Loch-Skerrols[2] Thrust of Islay belongs to the epoch of secondary movement which developed the Islay Anticline. It is probably a continuation of the Moine Thrust, so well known farther north.

Two important tracts of the South-West Highlands are not dealt with in this paper:—

(1) The narrow belt of volcanic and fossiliferous rocks commonly styled the Highland Border-Rocks; and
(2) The foreland of the Loch-Skerrols Thrust, as exposed in Islay and Colonsay.

[1] The dated references in the sequel are amplified in the Bibliography, App. I, p. 125.
[2] Scottish localities not shown in Pl. I are catalogued in the Locality-Index, App. II, p. 127.

Fig. 1.—*Secondary folding of nappes.*



It was in 1914 that I arrived at what are virtually my present conclusions. For some years previously my thoughts had ever turned to the difference characteristic of the two sides of the Loch-Awe Syncline, below the level of the Ardrishaig Phyllites (Pl. I).[1] It seemed fairly certain from the beginning that a thrust (or lag) was in some way responsible; but it was not until shortly before the outbreak of war that I attained to anything approaching full illumination. In the hope that someone else might finish the work if I should not be able to do so, I summarized the leading facts and suggestions as an appendix to a paper on the Islay Anticline published, during my absence, by this Society. However, this proffered page-long appendix was refused, on the ground that it was incomplete.

Clough's Secret of the Highlands.

I wish to take this opportunity of acknowledging that the interpretation of the South-West Highlands, sketched in the preceding section, is essentially a continuation of C. T. Clough's interpretation of Cowal. To mention but one of his claims on our gratitude, Clough will always be remembered as having introduced a new element of technique into the investigation of Highland problems. Everybody, since the dawn of geology, has employed eroded anticlines and synclines in the elucidation of stratigraphical successions and variations in relatively undisturbed regions of low relief. Clough boldly extended their use to the investigation of the folded complexes of the Highland Schists, where close study of a comparatively late anticline or syncline may throw invaluable light on the scope and character of earlier folds and systems of folds. Long before his day the Cowal Anticline had been recognized as a conspicuous feature of South-West Highland geology (1861 *a*, p. 135). After very detailed consideration of this structure, Clough states his conclusions regarding it as follows (1897, p. 83):—

'There is no doubt that this anticline is a true arch of an early foliation. Later foliations and other structures have been developed together with it . . . .; but the most prominent foliation of the district, and an enormous amount of folding of the same age as this foliation, were already in existence before it, and were folded by it.

'It is clear then that "the anticline" cannot be a simple or exact anticline of bedding. It should rather be looked on as an anticline of the limbs and axes [Clough means axial planes] of the early folds which affect the bedding. To what extent it departs from being an anticline of bedding must depend on the amount of this early folding.'

He then proceeds to gauge the effect of the early folding by comparing the outcrops encountered on the two sides of the Cowal Anticline. The contrast is shown to be remarkable, wherefrom he derives the suggestion that

'there is a great folding of "pre-anticline" age, which, roughly speaking, counterbalances the effect of "the anticline"'

(1897, p. 86 & pl. x). An unfortunate vagueness of many of

[1] See also 1922, Report A, par. 6.

the lithological distinctions in the critical region prevents Clough from speaking 'with much confidence' (1897, p. 87) of this supposed important pre-anticlinal folding; but he is of opinion that in the neighbourhood of Carrick Castle the fold can be traced with fair certainty, as may be judged from his mapping between Loch Goil and Loch Eck (Sheet 37), and his explanatory section (1897, p. 204).

We now know of several much clearer examples in the Highland Schists of secondary folds affecting earlier recumbent folds (fig. 1). Clough stands as the original interpreter of this great Secret of the Highlands—although, as he himself admits, the reality of the Carrick-Castle Fold cannot be regarded as beyond question.

One word more in this connexion. It is undoubtedly true that secondary anticlines and synclines are of more importance to workers in the Scottish Highlands than to others who have really big mountains and deep valleys to assist them; but such secondary folds are by no means overshadowed, even among the greatest mountains of Europe: a geologist on the shores of the Lake of Geneva may examine at his ease structural units higher than anything that erosion has spared on the summit of Mont Blanc.

Slides recognized.

There was one important feature of Highland geology that Clough did not realize during his examination of Cowal, namely, the inconspicuousness and, at the same time, the abundance of fold-faults, or slides, as they are called (1897, p. 88). The slides of the Southern Highlands took place for the greater part under conditions leading to constructive metamorphism, and in consequence are much less marked by localized belts of sheared and mylonitic material than their fellows of the North-West. It is not that indications of intense movement are lacking in the vicinity of the slides. On the contrary, they are universally present, but not necessarily in a more pronounced degree than elsewhere in the neighbourhood.[1]

In 1908, very clear evidence north of Loch Leven, in the Ballachulish district, revealed to me a slide, the continuation of which, I felt certain, traversed Glen Etive, some 8 miles away, at a locality already mapped in the most minute detail by Clough himself (1909, p. 53). Naturally, Clough was incredulous that what he had missed on the spot could be seen from a distance. But he visited the exposures north of Loch Leven, and, after satisfying himself that they left no room for doubt, he assured me that the district would become an object of pilgrimage to an extent greater than the North-West Highlands had ever been, for the story that it had to tell was much more wonderful.

[1] See also 1922, Report A, par. 10.

Nappes and their Travels.

Definition of a nappe.—In 1909 a little party of Scottish geologists was introduced to the wonders of the Pre-Alps under the able guidance of Dr. L. W. Collet, now Professor at Geneva. I well remember a comment by Mr. H. B. Maufe on this occasion:

'Alpine geologists speak and think of nappes, while Scottish geologists have been accustomed to concentrate their attention upon thrust-planes.'

In the Southern Highlands, a combination of the two habits of thought has proved advantageous. It is convenient to bestow titles upon important structural masses, selecting for the honour a nappe, a fold-core, or an entire fold, as the case may be; it is also convenient to give names in certain cases to major slides, both thrusts and lags.

On a previous occasion I have discussed the use of various tectonic terms (1916, p. 25); but nappe was not included, since I wished to present the main structural features of the district considered without reference to such abstruse matters as original order of succession and direction of movement. On the present occasion I am venturing to express an opinion on these difficult subjects, and accordingly offer a definition of the word nappe, as follows:—A nappe is a mass brought forward to a notable extent by recumbent anticlinal folding or by thrusting. In deciding upon the basal limit to be assigned to any particular nappe, one generally chooses some prominent thrust-plane; failing this, one is entitled to select the axial plane of some recumbent anticline or syncline, according to local convenience.

Direction of Movement defined and discussed.

The definition of nappe given in the preceding section depends upon a proper understanding of the words brought forward. It may be of service to offer a few remarks in this connexion. Often the rocks of a district, considered as a whole, show evidence of marked horizontal compression at right angles to some particular line of strike; while, considered in detail, they reveal a differential horizontal movement of their upper layers as compared with their lower. In such a case, movement is said to have occurred in the direction in which the upper layers have travelled relatively to the lower. At the present time, this method of stating the facts is a well-rooted convention, associated with a dependent terminology including such familiar expressions as foreland and foredeep.

How line of movement is recognized.—A few words may now be added regarding the criteria by which a geologist judges of the direction of movement. In the first place, the line of movement is at right angles to the strike of folds developed by the movement, or is established even more immediately by striation of thrust-planes. In this connexion only one comment is necessary.

The strike of folds is very conspicuous in the case of small-scale steep folds, but is very elusive in the case of big-scale recumbent folds. With the latter, all one can do is to determine the more or less sinuous[1] line, along which each particular fold closes upon some well-marked constituent member serving locally as its core. While recognizing the difficulty of the subject, I suggest that the greater folds of the Highlands seem to run roughly north-east and south-west in agreement with the lesser folds, by which they are so conspicuously accompanied and sometimes affected. Three examples pointing to conformity of strike will be noticed here:—

(1) As already set forth, Clough accounts for the contrast on the two sides of the Cowal Anticline by suggesting that this anticline arches a sequence profoundly influenced by big-scale folding of earlier date (figs. 1 & 4 & Pl. I). As the difference referred to persists across the Highlands, it would seem that Clough's early and late folds must have had very similar lines of strike. This is the more likely, since he recognizes countless small-scale 'pre-anticlinal' folds conforming in strike to the line of the anticline, and associated with contemporaneously-developed stretching and rodding approximately at right angles to the same line (1897, pp. 16, 17).

(2) In like manner, I attribute the marked differences met with on the two sides of the Loch-Awe Syncline at levels below the outcrop of the Loch-Awe Nappe to early flat folding and thrusting,[2] which here again must have agreed fairly closely in strike with the relatively late folding that developed the syncline (figs. 1, 4, & Pl. I).

(3) There is much in the gape of the Ballachulish Fold, as exposed along the north-western limb of the relatively late-formed Glen-Creran Syncline between Lairigmor and Loch Creran (1910 *a*, pl. xlii), which does not reappear to the south-east either in Glen Coe or in the Windows of Etive.

How direction along line of movement is recognized.—Once the line of movement is known, the next question is the actual direction along this line. Trustworthy vertical structures are rare in undisturbed rocks, else their deformation would serve as an invaluable index. Let us consider for a moment the section below the Moine Thrust, as exhibited at the base of the Stack of Glen Coul in Sutherland. An outcrop of Cambrian quartzite occurs there, resting unconformably upon Lewisian Gneiss and dipping beneath the Moine Nappe with the same inclination as that which characterizes the intervening thrust-plane. In the quartzite are numerous annelid-tubes—the well-known 'pipes,' as they are called. In the undisturbed foreland these pipes are always at right angles to the bedding of the quartzite. In this particular exposure they have been sheared into a very oblique position, and

[1] Without entering into detail, I may point out that I suspect that the west-north-westward close of the Beinn-Udlaidh Fold (1912 *b*, pp. 168, 169) is a misleading local feature of a fold which, viewed in its entirety, closes towards the south-east.

[2] See also 1922, Report A, par. 6.

their upper parts have travelled markedly farther to the north-west than their lower. Charles Callaway clearly realized the significance of this phenomenon (1884 *a*, p. 221), as also did Dr. B. N. Peach & Dr. J. Horne, who met its counterpart in another locality (1884 *b*, p. 34; 1907 *b*, p. 481).

But such weathercocks are seldom available. More often one has to rely upon the obvious relationship that isoclinal anticlines close in the direction of the movement of which they are a record. Where the folding has not a recumbent tendency, the application of this rule may present no special difficulty. As an example, one may cite the outward movement from the fan-axis of Loch Awe (P. Macnair, B. N. Peach, and others), with which may be grouped the south-eastward movement of the Cowal Anticline (Clough), and the north-westward movement of the Islay Anticline (Bailey).

In the case of recumbent folds, the recognition of the direction of movement is often more difficult, since the distinction of anticlines and synclines may involve careful research. The general rule is that anticlines are characterized by cores of relatively old rocks, and *vice versa*. Basing my argument upon this rule, I venture to suggest that the recumbent fold of Ben Lui (Pl. I) is a syncline, which, closing as it does towards the north-west, indicates movement towards the south-east. There are, however, a few notable exceptions to the general rule just stated. In 1907, Sarasin & Collet (1907 *c*, pp. 586–89) explained why they no longer opposed the cumulative evidence of Dr. H. Schardt and Prof. M. Lugeon in regard to the northward movement of the Pre-Alps. Their original difficulty had been the existence in the Zone des Cols of apparently anticlinal folds closing towards the south. They later realized that these folds had been involved in an exceptionally complex series of movements. I should myself describe them as secondary recumbent synclines developed in a sequence previously inverted.

Fortunately, one is not restricted to age-relationship in the recognition of recumbent anticlines. Clough, for example, developed a most ingenious method of attacking this difficult problem. He found that he could distinguish innumerable diminutive folds of 'pre-anticlinal' age in Cowal, and that, of these folds, those closing towards the south-east showed a great tendency to have their lower limbs attenuated and correspondingly lengthened (fig. 2, p. 90). On the ground that general experience teaches us that it is anticlines that preferentially exhibit attenuation of their lower limbs, Clough identified these south-eastward closing folds as anticlines; from which, of course, he deduced a south-eastward direction for the originating movement. (Like certain other deformational indices, this one, interpreted empirically, survives inversion, as the reader will realize if he turns fig. 2 upside down.)

A difficulty in the way of applying Clough's rule is the fact that in nature the tendency to attenuation is by no means restricted to

one limb of an isoclinal fold.[1] Clough was fully conscious of this difficulty, so far as small-scale folding was concerned, but he was not deterred thereby from arriving at a positive conclusion in the particular case just considered.

In the Ballachulish district I found the phenomenon of eddying forward motion illustrated on a big scale: that is, I found important slides of two kinds, both thrusts and lags (1910*a*). Of the two I should expect the thrusts, as a class, to be predominant, and on this account (among others) I have for many years inclined to the view that the Ballachulish and Fort-William Slides are thrusts rather than lags (1910*b*). If these two slides are thrusts, then here again the movement has been towards the south-east, as shown by the direction of close of the associated folds.

Fig. 2.—*Clough's criterion of south-eastward movement during 'pre-anticlinal' times in Cowal.*

It will be noticed that little or no attention has been directed in this discussion to the inclination of thrust-planes as a guide to the direction of movement. With the 'double fold' of the Glarus, and numberless other instances, in our minds, we are well advised to preserve a very cautious attitude in this matter. Where schuppenstruktur is clearly developed, as in the North-West Highlands so faithfully portrayed by Dr. B. N. Peach & Dr. J. Horne, the upward forward inclination of the individual scales, relative to the major thrusts above and below, affords a much more trustworthy indication. Schuppenstruktur is, moreover, a packing phenomenon appropriate to a compressed uninverted sequence. It differs in this respect from the attenuation-phenomenon illustrated in fig. 2. One might hope, therefore, in a region of recumbent folds to find some analogue of schuppenstruktur predominant in one set of limbs and indications of

[1] Another difficulty is that attenuation is in part a solution effect, for Clough found it commonly more marked in regard to the quartz than to the mica of a deformed band (1897, p. 22).

attenuation in the other, and this, of course, would at once betray the direction of movement. It is disappointing, therefore, to find Clough quite definite in his assertion that fig. 2 represents the general state of affairs in both limbs of his Carrick-Castle Fold. (At the end of Chapter VII, 1897, p. 82, Clough, for quite other reasons, contemplates the inversion of the early folds and accompanying foliations of Cowal by the Carrick-Castle Fold. Such inversion, if superinduced upon a previous inversion, might well account for the absence of anything approaching schuppenstruktur. But Clough wholly neglects this suggestion of his elsewhere in his account, and I do not think that it should be regarded as an integral part of his interpretation.)

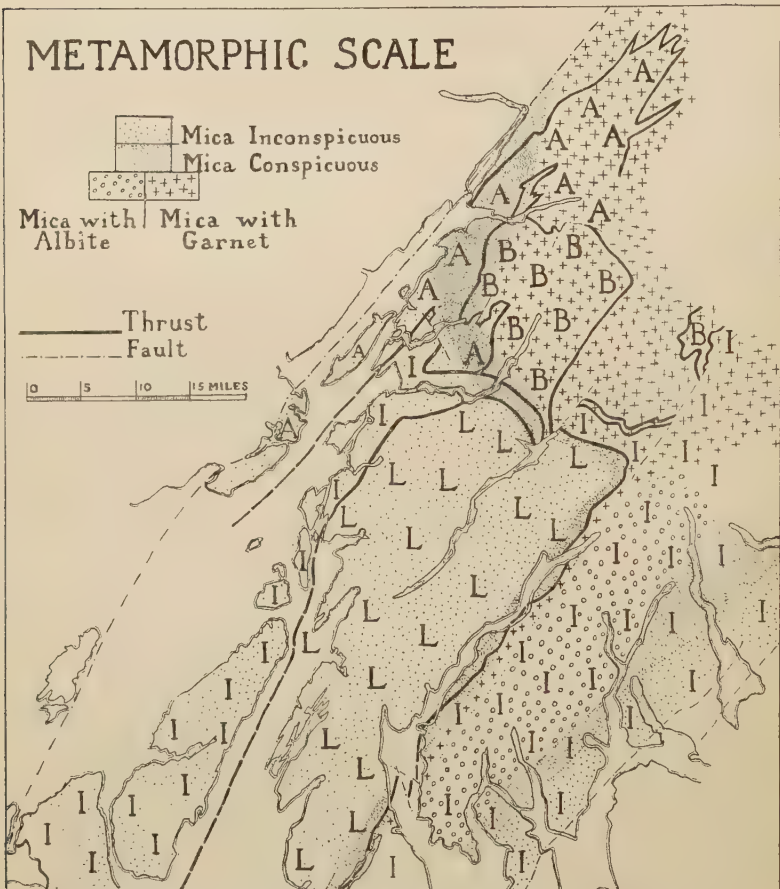
The intensive study of our North-West Highlands by Dr. Peach & Dr. Horne, and the contemporaneous investigation of the more ample exposures of Scandinavia by Törnebohm, alike emphasize another important aspect of the matter. On approaching a mountain-chain from the front, one commonly finds the original structures of the rocks of the foreland increasingly deformed. Locally, the condition of the rocks of the South-West Highlands is difficult to reconcile with this familiar experience. I have already partly indicated the evidence of persistent south-eastward movement during the main period of nappe-formation. As indicated in Pl. I, the Loch-Awe Nappe is interpreted as a klippe, or outlier, resting on the Iltay Nappe. Naturally, one might expect less evident distortion of the rocks of the Iltay Nappe in Cowal than in Islay, but the reverse actually occurs. In Islay many outcrops of flagstone are known with ripple-marks still perfectly preserved; in Cowal such original details are lost sight of in the general deformation. As a tentative explanation, I suggest that local conditions, including temperature, may have been the determining factor in producing this anomaly. The Cowal region may have been more heated than the Islay region, and accordingly more inclined to react generously and diffusely to mechanical stimulus.

There remains but one other important source of information that need be touched upon, and that is the facies of far-travelled nappes. Igneous, as contrasted with sedimentary, facies helped Hutton long ago to establish the subterranean origin of the lava-flows of Scotland. Alpine, as contrasted with Helvetian, facies helped Dr. Schardt in much more recent days to realize the southern origin of the great invading nappes of his native mountains. As in the Alps, so in the South-West Highlands, considerations of facies are of great importance. They do not, indeed, tell us from which direction the Loch-Awe Nappe travelled into its present position; but they do warn us against supposing this nappe to have spread in mushroom fashion from a root beneath. If the Loch-Awe Nappe originated as a mushroom, one would expect it to reproduce in itself the Islay facies; but such is not the case.

Metamorphism.

The metamorphism of the South-West Highlands is too wide and speculative a subject to be dealt with here in anything more

Fig. 3.—*Metamorphism of nappes.*



[The nappes, in descending order, are lettered: L=Loch-Awe Nappe; I=Iltay Nappe; B=Ballachulish Nappe; A=Appin Nappe. The metamorphic scale adopted refers only to the condition of normal grey pelitic sediment.]

than the merest outline. The suggestions offered below will, it is hoped, be amplified on some future occasion:—

(1) Fig. 3 furnishes a graphical statement of the metamorphism of normal grey pelitic (or semipelitic) sediments in the South-West Highlands.

(2) In such rocks increasing metamorphism leads from slates and phyllites through mica-schists into either garnetiferous mica-schists or albite-schists.

(3) In rocks of a different composition (as, for instance, quartzite, limestone, or even carbonaceous or calcareous pelitic sediments) response to metamorphic influences may not agree very closely with what is shown in fig. 3. Thus the Ballachulish Quarries yield black roofing-slate, although situated on the margin of the garnetiferous zone of fig. 3 (1916, p. 202).

(4) A vague agreement between the outcrops of successive metamorphic and structural zones, respectively, lends distinct support to a theory of metamorphism controlled by depth-temperature, such as was developed by Clough (1897, p. 91) to account for the relatively high metamorphism characteristic of the axial belt of the Cowal Anticline (see figs. 1 & 3).

(5) The agreement noted above is so incomplete that no increase of metamorphism accompanies the emergence of nappes north-west of the Loch-Awe and Glen-Creran Synclines. This capriciousness suggests recourse to Mr. G. Barrow's theory of metamorphism controlled by temperature dependent upon magmatic distribution (1912 *a*). To me, there seems to emerge no reason against combining Clough's and Barrow's interpretations.

(6) Fig. 3 shows sufficiently clearly that crystallization continued until the close, at least, of the main nappe-movements: there are no marked metamorphic inversions.

(7) Clough did much to distinguish certain mineral developments of Cowal as of pre-anticlinal, or anticlinal, date, respectively (1897). I have now found good evidence of the development of albite in the albite-schists of Cowal during both these periods. As albite-development is due to specialized conditions of regional metamorphism (hydrothermal, according to E. H. Cunningham-Craig, 1904 *a*, p. 26), it looks as though the early and later movements classified in fig. 1 should be regarded as successive chapters in a long-continued history of mountain-building. Among the products of the later movements is the Loch-Skerrols Thrust, which I correlate with the Moine Thrust of the North-West Highlands. Accordingly, I am led to suspect a fairly close connexion between the south-eastward movement of the great nappes of the South-West Highlands and the north-westward movement of their better-known fellows of the North-West Highlands. Naturally, this opens the door for comparison of the Southern Highland nappes with those which will for ever be associated with Törnebohm's name in Scandinavia. Moreover, if one is ready to look beyond the limits of Caledonian time, one is tempted to trace an analogy between the north-westward movement revealed in Islay and the back-movement of the root-region of the Alpine Chain towards the Plain of Lombardy.

Corrigenda since 1910.

From 1910 onwards the Geological Society has published a series of papers on South-West Highland tectonics, written by myself, and one describing the structure of the Glen Orchy district, in which I collaborated with Mr. M. Macgregor. All told, these papers cover more than half of the area dealt with on the present occasion. Their detailed descriptions and their beautifully reproduced maps are available to anyone who wishes to realize the full appeal of the interpretations here advanced. It is, therefore, important to assist the reader by enumerating at this juncture such modifications as have come in the wake of our steadily increasing knowledge.

1910. Recumbent Folds in the Schists of the Scottish Highlands.—This paper deals with the recumbent folds of Ballachulish, Aonach Beag, and Appin, north and west of the granite-mass of Etive; their

attendant slides; and their liability to secondary folding. The reality of all these geological features is, I consider, unassailable by anyone acquainted with the field-evidence. At the same time, I should like to notice certain important modifications which I have been able to effect as a result of continued enquiry. For instance, the Eilde Flags of the Loch-Eilde Mor outcrop are no longer referred wholly to the upper limb of the Appin Fold (see 1916, figs. 9–10, and 1910 *a*, pl. xliii); while the limestone at Loch Dochard, east of the Etive Granite, is now definitely relegated to a lower structural position than the Appin Core.

The two changes just mentioned, along with much else of importance, are due to later work by Mr. R. G. Carruthers. Whereas I had already ventured to correlate flags of two important outcrops, the one running past Loch Eilde Mor, the other through Fort William, I confess that I did not think that these outcrops had any underground connexion in the intervening country (1910 *a*, p. 616 & pl. xliii)—although I was well aware that my evidence in this matter was inconclusive. Mr. Carruthers was fortunate enough to find that a persistent south-westward pitch causes a remarkable zigzag approach of the Loch-Eilde and Fort-William outcrops in the district beyond that which I had examined, and I now agree with him that an underground connexion is highly probable. As an incident of the zigzag approach just mentioned, Mr. Carruthers noted folding of the Fort-William Slide. I am of opinion—but I admit Mr. Carruthers attaches little weight to my suggestion—that the Meall a' Bhuirich Slide in its type-exposure is merely the folded continuation of the Fort-William Slide. My original view that the Meall-a'-Bhuirich Slide reappears east of the Loch-Eilde outcrop (1910 *a*, *h*, pl. xlii) I frankly disavow. Pl. I shows the approach of the two outcrops of Eilde Flags, and, in so far as it is a continuation of my previously published mapping, it is mainly based upon Mr. Carruthers's work [1]—except, of course, that I am alone responsible for the expressed suggestion that the Fort-William and Meall-a'-Bhuirich Slides are one and the same. The correction has two very pleasant features: looking back, one realizes anew that what has proved impossible to unravel in some particular region may be an easy matter to distinguish in an adjoining district; looking forward, one hopes that some of the remaining elements of doubt may in their turn be dispelled, so soon as opportunity arises for further extension of the field of mapping.

Mr. Carruthers's other points need not detain us long, since I have no strong opinion in regard to them, and have modelled my present account on non-committal lines. They may be summarized as follows:—

p77-92.

(1) Mr. Carruthers thinks that he can locally (that is, in the Kinlochleven district) distinguish three mica-schists and three quartzites, intervening between the Ballachulish Limestone and the Eilde Flags—where previously I only had recognized one group of each, namely, the Leven Schists and the Glen-Coe Quartzite. I have discussed these two alternative interpretations elsewhere (1916, p. 62). Here, in order to avoid uncertainties, I treat the mica-schist and quartzite complex as one great stratigraphical group (Pl. I). In regard to the structural relations, which this inclusive group bears to the Ballachulish Limestone, on the one hand, and the Eilde Flags, on the other, Mr. Carruthers and I are in very close agreement. I have myself dealt more particularly with the limestone side of the complex, while Mr. Carruthers has gathered much of the information regarding the behaviour of the flags.

(2) Mr. Carruthers thinks that the rocks shown as belonging to the Sub-Eilde Complex in Pl. I are stratigraphically distinct from any of their fellows in the neighbourhood. I have already discussed this difficult question (1916, p. 62), and meanwhile do not intend to resuscitate it. In the present paper I merely use the outcrops of these rocks as indicating a lower structural level than is reached in the Loch-Eilde outcrop of the Eilde Flags, without

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[1] For permission to publish this material I thank Mr. R. G. Carruthers, as well as the Director of H.M. Geological Survey.

expressing any opinion as to their stratigraphical equivalents. I am very sorry that Mr. Carruthers's important contribution is not yet fully published. If it were, I am certain that it would be easy to criticize some of his statements—to judge from a preliminary notice (1913 *a*, p. 51); but of its value as a whole there can be no question.

It may be well to add that there was always an essential difference of status in regard to the 1910 interpretation of the folded district of Kinlochleven (now admittedly wrong in important particulars), and that of (say) Ballachulish. The former was based on what seemed a mere sufficiency of evidence; the latter upon the reiterated testimony of section after section. In the Kinlochleven district I am now of opinion that I made one cardinal mistake—I interpreted a syncline with steeply-inverted pitch as an anticline,—and the realization of this has left an insufficient foundation for a complete structural interpretation. No similar isolated accident could affect the reading of the Ballachulish Fold and Slide.

As regards other corrections of the work covered by my 1910 paper I may refer to:—

(1) The elucidation of additional details concerning the Ballachulish Fold near the head of Loch Creran (see 1914 paper).

(2) The much more important recognition of the extension of the Iltay Nappe to the shores of Loch Creran, where previously I had, with very imperfect knowledge of the ground, imagined that nothing but a local facies of part of the Leven Schists occurred. This point is dealt with in detail later on (p. 115).

1912. The Glen-Orchy Anticline (E. B. Bailey & M. Macgregor).—There is no correction to emphasize with regard to this paper. In order to avoid criticism, the quartzites, mica-schists, and limestone of the Beinn-Udlaidh and Loch-Dochard exposures are ascribed in the sequel to the Sub-Eilde Complex without definite stratigraphical correlation.

1913. The Loch-Awe Syncline.—I no longer regard the St. Catherine's Graphite-Schist and its immediately associated phyllites, or mica-schists, as in stratigraphical continuity with the Ardrishaig Phyllites (1913 *b*, p. 299). This involves, among other things, the separation from the Ardrishaig Phyllites of certain calcareous mica-schists, which are shown (1913 *b*, pl. xxxii) as extending northwards and eastwards from Meall nan Tighearn (around Ben Lui). The Erins Quartzite I still believe to be connected stratigraphically with the Ardrishaig Phyllites (p. 96).

1914. The Ballachulish Fold near the Head of Loch Creran.—This paper supplies certain corrections to its predecessor of 1910.

1917 (for 1916). The Islay Anticline.—Nothing further has been published.

II. The Three Great Structural Divisions.

A concise treatment will now be given of the stratigraphy and structure of the South-West Highlands. Discussion based upon detailed accounts of certain crucial sections is reserved for § III.

The Loch-Awe Nappe.

Constitution.—The structural independence of the Loch-Awe Nappe cannot be appreciated without extensive trespass into the country surrounding the nappe. Discussion of this cognate matter is, therefore, reserved for a later paragraph. Meanwhile,

the reader is asked to excuse a rather dogmatic statement of the case.

The outcrop of the nappe reaches south-westwards from the northern end of Loch Awe, until lost sight of under the sea. Its breadth is roughly 20 miles, and its position is clearly indicated in Pl. I. The stratigraphical succession within its limits is as follows:—

Loch-Awe Group. (Pebbly character recurrent.)	Loch Avich, green Slates with grits, and (in the basal part) pillow-lavas.
	Tayvallich, black Slates and limestones (both often pebbly), grits, conglomerates, and pillow-lavas. The rock-fragments in the conglomerates are generally of local origin; but, in certain well-known occurrences, nordmarkite and other foreign boulders are found.
	Crinan Grits and Quartzites with subordinate slates and limestones.
Ardrishaig Group. (Pebbly character very restricted.)	Shira Limestone, grey or cream-coloured, according to locality; absent south of the Crinan Canal, and, elsewhere, often interbedded with greenish-grey phyllites.
	Ardrishaig, soft, greenish-grey Phyllites, with calcareous lenticles, occasional beds of buff-coloured or white limestone, and a fair proportion of compact, fine-grained, slightly-calcareous quartzite.
	Erins fine-grained, slightly calcareous Quartzite, restricted to Lower Loch Fyne.

Basic sills (epidiorite) are abundant everywhere, except in the central portion of the outcrop of the Loch-Avich Slates.

The separation of the Loch-Awe and Ardrishaig Groups is due to Mr. J. B. Hill (1899, p. 473). The subdivision of the Loch-Awe Group (1913 *b*, p. 291) followed closely on Dr. B. N. Peach's recognition of volcanic rocks in the Tayvallich Peninsula (1904 *b*, p. 68).[1] The Erins Quartzite was early distinguished by Mr. Hill: he regarded it as a local facies of the lower part of the Ardrishaig Group. I am inclined to think that it is a separate entity, and that it owes its restricted occurrence to limitation by the thrust at the base of the Loch-Awe Nappe.

At one time, I imagined (1913 *b*, p. 300 & pl. xxxii) that the Erins Quartzite probably belonged, half to the Ardrishaig Group, and half to the Ben-Lui Group (p. 95). This working hypothesis was based upon a couple of rather insecure foundations:—

(1) A tentative correlation, connecting certain graphitic phyllites at Stronchullin, in the heart of the Erins Quartzite, south of Ardrishaig, with similar rocks occurring in bands at the north-western margin of the Ben-Lui Group, 18 miles farther up Loch Fyne.

(2) A tacit assumption that the Stronchullin outcrop does not mark the centre of a fold.

Now that other evidence points to a complete structural separation of the Ardrishaig Phyllites (Loch-Awe Nappe) from the Ben-Lui Schists (Iltay Nappe), partition of the Erins Quartzite is no longer possible.

[1] See also 1922, Report A, par. 1.

Original order of deposition.—Two items of evidence indicate that the column on p. 96, with Loch-Avich Slates at the top and Erins Quartzite at the bottom, represents the original order of deposition of the rocks of the Loch-Awe Nappe.

(1) In the Tayvallich Peninsula, the Tayvallich Slates, Limestones, and Lavas very clearly overlie the Crinan Quartzite. Where the volcanic escarpment reaches the sea, the second lava from the bottom has numerous pipe-amygdales springing from its base, while its upper portion is thoroughly slaggy. I have always agreed with Dr. Peach that this lava is 'right way up,' and growing experience has strengthened my belief. Anyone who has spent much of his life among lavas, must have met with many examples of pipe-amygdales rising from the base of a flow, or from the base of an individual band or lenticle within a flow, but never descending from the top.

Dr. Peach has already published a horizontal section showing the position and relations of this invaluable Tayvallich Lava (1911, fig. 4, p. 69).[1] If this flow is 'right way up' (and who can doubt it?), then the field-relations show almost conclusively that the Tayvallich Slates and Limestones are of later date than the Crinan Quartzite.[2]

(2) At Kilmory Bay, J. S. Grant Wilson found the Ardrishaig Phyllites dipping steeply beneath a conglomeratic grit forming the base of the Loch-Awe Group (1911, p. 64). The grit has the appearance of being 'right way up,' for it includes a succession of seams of fine-grained conglomerate, all of them with well-defined bases and ill-defined tops. In this case, perhaps, it is wise to regard the evidence as suggestive rather than conclusive; but it gives valuable support to the testimony afforded by the pipe-amygdales mentioned in the previous paragraph.

Structure.—Small-scale isoclinal folding is often an obvious feature of the geology of the Loch-Awe Nappe. The isoclinal folds and the concomitant cleavage are disposed with a marked tendency to fan-arrangement—steep or vertical along an axial belt, and inclined inwards on each side. Despite all this, there is a fine simplicity in the surface-distribution of the rocks. The Loch-Avich Slates have an outcrop in the neighbourhood of Loch Awe, and the other subdivisions follow round about it in the order given in the table. This simplicity betokens a general synclinal or anticlinal structure for the district as a whole. Mr. Hill, who, as will be remembered, instituted the separation of the Loch-Awe and Ardrishaig Groups as two great stratigraphical units, always referred to the structure of the district as synclinal. I do not know what influenced Mr. Hill in this matter, but there are two very good reasons, which were open to anyone to make use of at the time when he wrote on the subject: the first is the upward structural succession encountered north-westwards from the flat central belt of the Cowal Anticline; and the second is the obvious emergence of the Ardrishaig Phyllites from beneath the outcrops of the Shira Limestone and Crinan Quartzite where these latter terminate northwards across the general strike of the folding.

My own observations afford additional proofs of the existence of

[1] I am not certain that the photograph (1911, pl. iv) was not taken, by mistake, of an overlying lava.

[2] See also 1922, Report A, par. 3.

the Loch-Awe Syncline. They show ascending structural successions towards the Loch-Awe country in the adjoining districts of Islay and Glen Orchy (1917, 1912 *b*),[1] and also an upward structural succession from Crinan Quartzite through Tayvallich Slates into Loch-Avich Slates within the limits of the Loch-Awe Nappe (1913 *b*, pp. 292, 294; 1911, pp. 65–68).[2]

There is nothing in what has been noted above that suggests bodily transport of the Loch-Awe Nappe. The obvious fan-folding may be taken as a typical example of movement outwards in two directions from a central axis. Such movement would not be expected to belong to a period of advance of the nappe as a whole; it seems connected rather with the synclinal depression which affected the nappe after its mise en place. Anticipating much that has yet to be discussed, one may state that the Loch-Awe Nappe travelled into its present position from the north-west. The evidence relied upon is afforded by the distortion of the underlying rocks, leading, among other results, to the production of the recumbent syncline of Ben Lui (Pl. I & fig. 4, p. 102).

The Iltay Nappe.

Constitution.—The following succession has been traced in that part of the South-West Highlands which is fashioned out of the Iltay Nappe (Pl. I):—

Leny Grits with slates (or phyllites) of the Aberfoyle type.

Aberfoyle (or Dunoon) grey, green-grey, buff-coloured, purple, and black Slates (or Phyllites) with numerous thin limestone- and grit-bands.

Ben-Ledi (or Beinn-Bheula) Grits, grey phyllites (or mica-schists), and albite-schists (or gneisses), with locally important chlorite-epidote-schists (Green Beds). Garnets are common north-east of the albite-zone (fig. 3). Oligoclase-pebbles are often said to be characteristic of the Ben-Ledi Grits; my experience is that the common felspar-pebbles are albite and more or less perthitic orthoclase.

Green-Bed Group, in which chlorite-epidote-schist, often gritty, is strongly developed. Hornblende is common north of Cowal.

Pitlochry (or Glen-Sluan) Schists and Grits. The schists carry albite in Cowal and garnet farther north (fig. 3).

Loch-Tay light to dark grey crystalline Limestone (or marble), sometimes mottled with black calcite-crystals; in large part a calcareous schist or quartzite. Almost always invaded by epidiorite-sills.

Ben-Lui Garnetiferous Mica-Schist with grits and minor Green Beds; graphite-schists, interbedded with phyllitic garnetiferous mica-schist, mark the edge against the Ben-Lawers Group in the St. Catherine's district of Upper Loch Fyne. Limestone also occurs. In the district of Lower Loch Fyne garnets are but poorly developed.

Ben-Lawers Calcareous Schists (or phyllites), with some limestone and fine-grained quartzite. The calcareous material is disseminated, and is often only clearly visible in quartzose lenticles.

Easdale black graphitic Slates (or Schists), with subordinate bands of quartzite and black limestone. cf. St Catherine's schists.

[1] See also 1922, Rep. A, par. 4.

[2] *Ibid.* Rep. A, par. 2.

- Transition Group, including Black Slates and Quartzites. Conglomerates occur in Scarba, Jura, and Islay, and grey phyllite (Port Ellen Phyllites) in Southern Jura and Islay. There are also limestone-bands, sometimes pebbly.
- Islay Quartzite in part pebbly, especially towards the margin of the Transition Group: locally, a flaggy dolomitic group occurs within the quartzite not far from the Portaskaig Conglomerate (Northern Islay); locally also, a flaggy semipelitic pebbly group develops not far from the Transition Group (Northern Jura, Scarba, etc.).
- Portaskaig Conglomerate, with nordmarkite and other boulders.
- Islay dark-grey Limestone, locally oolitic; this limestone and the Mull-of-Oa Phyllites are to some extent interbedded.
- Mull-of-Oa grey or greenish Phyllites with dark colour-striping; thin cream-coloured sandy dolomites are common in some exposures.
- Maol-an-Fhithich fine-grained Quartzite.

It must not be thought that the succession outlined here is to be met with as a whole in any one locality in the South-West Highlands. The constitution of the Iltay Nappe varies notably from place to place, according to the positions of the thrust-planes which serve as its boundaries above and below. The variation can be summarized as follows (see Pl. I):—

District.	Partial Succession.
(*a*) Islay Archipelago, north-west of the Loch-Awe Nappe.	Maol-an-Fhithich Quartzite to Easdale Slates.
(*b*) Kintyre and Cowal, south-east of the Loch-Awe Nappe.	Ben-Lawers Schists to Leny Grits (with a concealed underground continuation of the rocks of the Islay Archipelago).
(*c*) Strip connecting (*a*) and (*b*) round the northern end of the Loch-Awe Nappe.	Islay Quartzite to Easdale Slates.
(*d*) North-eastward continuation of (*b*) and (*c*) towards Loch Tay.	Islay Quartzite to Leny Grits.

N. of Dalmally & W of Ben Lui. [illegible]
[illegible]
[illegible]
[illegible]
Sheet 45 [illegible]
Mem. Sh. 45. [illegible]

The detailed evidence upon which I base my reading of the stratigraphy of the Islay Archipelago (*a*) has been recently explained in the Quarterly Journal of this Society (1917). It must be admitted, however, that Dr. Peach and Mr. Wilkinson previously put forward an interpretation differing in various important particulars (1907 *a*). The statement of the Kintyre, Cowal, and Loch-Tay sequence (*b* & *d*) represents the verdict of my predecessors—Clough, Cunningham-Craig, Macnair, Hill, Kynaston, and Grant Wilson. The three last-named are more especially responsible for tracing that part of the succession which extends through the Calcareous Schist (Ben-Lawers Group) into the Black Schist and Pebbly Quartzite cropping out farther north. The geology of the intermediate belt (*c*), complicated as it is by granitic intrusion, has not been adequately described as yet, and will accordingly be dealt with later on (p. 117).[1]

It will be readily understood, after what has just been stated, that definitely synthetic treatment is requisite to realize the full

[1] See also 1922, Report A, par. 8.

sequence of the Iltay Nappe as developed in the South-West Highlands—that is, so long as one is restricted to the use of local evidence. I am delighted to say that it is possible to arrive at the result more simply along a quite independent line of enquiry.

The same long stratigraphical sequence occurs in the South-Central Highlands, under conditions which render it relatively easy to read. Once read, its application to the South-West is a matter involving fairly obvious correlations. All this was realized many years ago by Mr. George Barrow (1913 *b*, p. 306; 1917, p. 160), whose sequence for the South-Central Highlands can be found on turning to Sir Archibald Geikie's first Presidential Address to this Society (1891, Proc. p. 74). It is, however, only fair to remind the reader that in the Central Highlands, as in the West, grave differences of opinion exist as to the interpretation of local successions. The question at issue is whether the Perthshire (Islay) Quartzite is part of the general sequence, or whether it is an unconformable unit. Mr. Barrow adopted the former alternative, and, after careful examination of the Pitlochry and Blair-Atholl districts, I have no doubt that he is justified by the nature of the evidence. As to the possibility of detailed correlation between the Central and the Western Highlands, there has long been sufficient excuse for optimism. Macculloch did well, when he wrote in 1819 of his discovery of a schistose conglomerate in the Garvellach Isles, 'which,' he said, 'will be seen hereafter to occur in Isla, and which I have also observed in Schihallien' (1819, vol. ii, p. 159). This conglomerate is characterized by its abundant nordmarkite-boulders, its frequent close resemblance to tillite, and its well-defined stratigraphical associates.

We may pass now to another important feature of the Iltay Nappe. Clough directs special attention to the recurrence of 'green beds' on widely different horizons in the Cowal succession (1897, p. 89). It is impossible to account for all these scattered outcrops by assigning them to a single group, reduplicated by folding—as a matter of fact, good examples occur on both sides of the Loch-Tay Limestone. Accordingly, Clough was impressed by the evidence which the repetition of this peculiar type of sediment affords of continuous deposition, from what he took to be the marginal portion of the 'Ardrishaig Phyllites,' well nigh to the Dunoon boundary of the Ben-Ledi Grits and Schists. On quite other grounds I have had to transfer some of Clough's 'Ardrishaig Phyllites' to the Ben-Lawers Group (p. 121); and, in default of more precise local evidence, I have been guided in mapping the line of the separating thrust by the improbability of 'green beds' continuing in Cowal across the boundary of the Iltay Nappe. At the same time, I think that Clough rather exaggerates the peculiarities of the 'green beds.' He compares them with the epidotic grits, etc., of the Lower Torridonian of Skye; he might have extended the comparison, I believe, to certain Ordovician sediments (for instance, the Tappins Group) figuring prominently in the Southern Uplands.

Original order of deposition.—Three reasons can be adduced for regarding the column on pp. 98–99 as arranged in descending order of age, with Leny Grits at the top and Maol-an-Fhithich Quartzite at the bottom:—

(1) Beannan Dubh, a little hill halfway along the eastern coast of Islay, is composed of an outlier of typical Portaskaig Conglomerate lying flatly upon an extensive outcrop of Islay Limestone. Sandy cream-coloured dolomites are conspicuous as intercalations in the conglomeratic series, and appear to have suffered 'contemporaneous erosion,' yielding fragments to the overlying interstratifications of conglomerate. One of these dolomite-bands, whiter than usual, can be traced for a couple of hundred yards. It has a regular base resting upon shale, and a highly irregular top with cavities choked by downward extensions from an overlying stratum of well-bedded gritty dolomite. Along the jagged junction there is often a foot or two of coarse breccia consisting of angular blocks of white dolomite enclosed in a brown gritty matrix (1917, p. 143).

There seems no room for doubt, when one is faced with this exposure, that the Portaskaig Conglomerate is here 'right way up,' and therefore of later date than the subjacent Islay Limestone.

(2) A very suggestive sequence, from grey slate, to black slate, to conglomerate—charged with black slate-fragments, to quartzite, is found at the southern extremity of Islay. I have described and figured the section (1917, p. 154), and need only repeat that this particular conglomerate appears to be younger than the associated black slate; and that such an inference, combined with my reading of the local stratigraphy, leads to the further conclusion that the Port-Ellen Phyllites (and therefore also the Easdale Slates) are younger than the Islay Quartzite.

(3) Clough's evidence for repeated south-eastward movement in Cowal has already been discussed (p. 89). It seems highly probable that his Carrick-Castle Fold (pp. 86 & 103) developed during some phase of these south-eastward directed disturbances. Accordingly, since the fold closes south-eastwards, it is natural to regard it as a recumbent anticline,[1] and to expect it to contain a core of relatively old rocks—in other words, to regard the Loch-Tay Limestone and its associates as older than the Ben-Ledi Grits and Aberfoyle Slates. It is only fair, however, to state that this apparently justifiable inference escaped Clough's notice. He did, indeed, refuse to follow the common custom of assuming that the reverse succession had been established; but his position was entirely negative—in fact, he said that the schists of Cowal had afforded him no clue whereby to determine their age-relations (1897, p. 86).

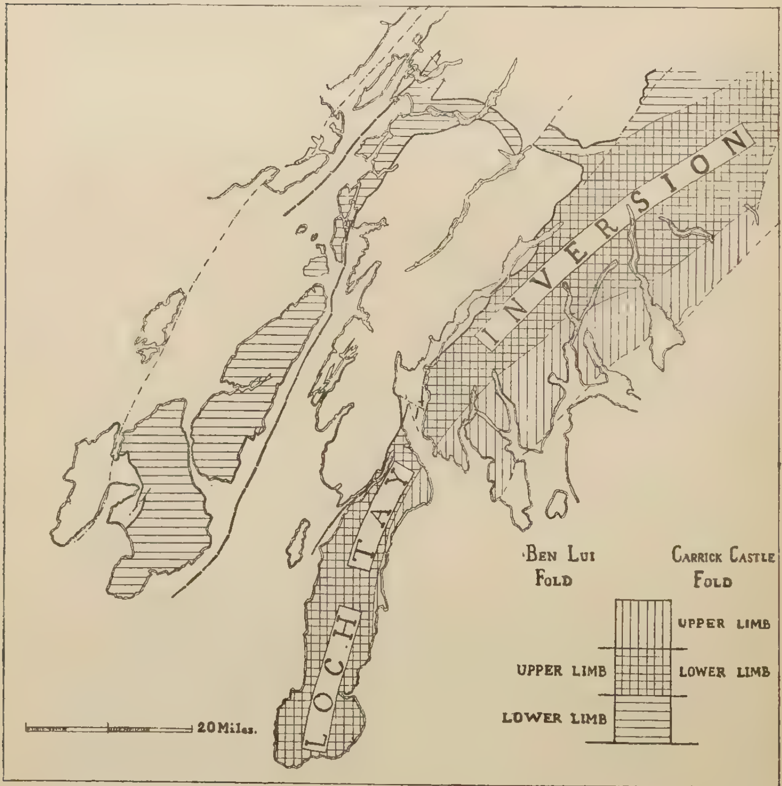
Passing reference has just been made to a prevalent opinion that the order of deposition is the exact reverse of that which is given above. I believe I am justified in saying that the sole foundation for this view is a widespread structural superposition of the Loch-Tay Limestone, Pitlochry Schists, and Green Beds upon the Ben-Ledi Grits and Schists in a tract of country reaching from Kintyre, north-eastwards past Loch Tay. When Sir Archibald Geikie, in his Presidential Address to the Geological Society, spoke of the Loch-Tay region (1891, Proc. p. 73), he said:

'It is difficult to resist the belief, though it would be premature to conclude, that this obvious and persistent order of succession really marks the original order of deposition.'

[1] The Carrick-Castle Fold closes downwards in its type-exposure, and Clough calls it a 'syncline.' The apparent contradiction is one of terms, not of ideas.

His words are very true, for in the interval few of the geologists who worked under him have resisted the belief, although Clough in this, as in so many other directions, was a notable exception to the rule. Clough pointed to his Carrick-Castle Fold as a warning, since structural superposition in the two limbs of this fold naturally gives contradictory results if it be employed as an index of relative age (1897, p. 86). With increasing knowledge of the complexity

Fig. 4.—*The two great folds of the Iltay Nappe.*



of Highland structure, it is not too much to say that the difficulty of resisting the temptation of arguing from superposition to relative age has steadily diminished. Clough's criticism can be applied with great force, for instance, in the comparison of the Loch-Tay region and the Islay Archipelago. Here, again, the order of the superposition in the one case is the very reverse of what it is in the other (fig. 4).

Structure.—If for the moment the results of secondary folding are set aside, the main structural features of the Iltay Nappe can be stated in a few words (fig. 4).

In its lower portion the sequence is predominantly normal. Thus, in Islay, the Islay Quartzite overlies the Portaskaig Conglomerate and Islay Limestone (1917, pl. xii); and, in conformity with this, all the way from Luing to Dalmally the Easdale Slates persistently separate the Islay Quartzite from the overlying Loch-Awe Nappe (pp. 114, 118, & 119).

At higher levels, recumbent folding sets in, as proved by an extensive inversion of Loch-Tay Limestone, Pitlochry Schists, and Green Beds over the Ben-Ledi Grits. The flat-lying geology of the Loch-Tay district, mapped by J. S. Grant Wilson (Sheet 46), has become too familiar to detain us; all that need be said is that the inversion of the Loch-Tay Limestone is revealed as holding good for some 15 miles measured across the strike. Far less famous, but equally instructive, is a set of exposures at Campbelton in Kintyre, where a restricted subsidence (perhaps of Tertiary date) has led to the preservation of a little coalfield in the axial regions of the Cowal Anticline. The Loch-Tay Limestone and overlying schists are seen to advance their outcrops notably to the east as they come within the sphere of influence of the depression, whether their approach to it be followed from the north or from the south. It was a great pleasure to me, on visiting the ground in 1919, to find how accurately R. G. Symes, with Dr. Peach's assistance, had traced the main exposures of limestone and associated epidiorite (Sheet 12): it was also delightful to realize on the ground how clearly the Loch-Tay Limestone overlies the Ben-Ledi Grits, etc., which constitute the main part of the peninsula of Kintyre, both north and south of the depression.

The normal sequence of Islay and the inverted sequence of Loch Tay are seen in conjunction on the slopes of Ben Lui. Together they supply the two limbs of a great recumbent fold (fig. 4)[1]; the normal sequence furnishes the lower limb, the inverted sequence the upper (p. 124). In such circumstances, as I have already pointed out, it is difficult to regard the Ben-Lui Fold as anything but a syncline, and since it can be seen to close towards the north-west, it has all the appearance of being a product of south-eastward movement (p. 89).

At still higher levels, the Loch-Tay inversion gives place to a normal sequence once again, this time through the intervention of the Carrick-Castle Fold, which (as might be expected) closes south-eastwards (p. 86). It has already been pointed out that this fold is probably an anticline, because of Clough's reading of the local evidence of south-eastward movement (p. 101); of course, if Clough's evidence were not available, the same result would have been arrived at on my reading of the original order of deposition.

[1] See also 1922, Report A, par. 5; Report B.

The secondary folding of the Iltay Nappe has been mentioned on several occasions already (fig. 1). One main feature is the synclinal fan of Loch Awe followed in relay by that of Ben Lawers. South-east of this lies the Cowal Anticline overturned (north-east of Aberfoyle) south-eastwards. On the north-west lies the Islay Anticline, overturned north-westwards in connexion with the Loch-Skerrols Thrust. It is important to realize that the relationship of the Loch-Skerrols Thrust to the Islay Anticline shows almost certainly that this particular thrust is of rather late date in Southern Highland history; and also that it originated during a phase of north-westward movement. There is additional and quite independent evidence for the inferred north-westward movement. The nature of the foundation which emerges from beneath the Loch-Skerrols Thrust is such as to suggest a correlation between this important dislocation and the Moine Thrust of Ross and Sutherland (1917, fig. 3, p. 138); and it is well known that the displacement along the Moine Thrust has been directed towards the north-west (pp. 88 & 90).

The Ballappel Foundation.

Constitution.—The Eilde Flags are one of the most important stratigraphical units of the Ballappel Foundation. For reasons already explained (p. 94), certain rocks situated on a lower structural level than the Eilde Flags of the Loch-Eilde Mor outcrop are classified in Pl. I as constituents of a Sub-Eilde Complex. In a stratigraphical sense the rocks of the Sub-Eilde Complex are *incertæ sedis*. Their cover, however, can be arranged in sequence as follows (1910 *a*, 1912 *b*, 1914, 1916):—

owest gp. Eilde Flags (commonly classed with the Moine Gneisses of the Central Highlands).

Quartzite and Mica-Schist assemblage including two certain members, the Glen-Coe Quartzite and the Leven Schists (Mr. R. G. Carruthers argues for six instead of two subdivisions, see p. 94). The Glen-Coe Quartzite is fine-grained, except that near the head of Loch Creran and in Glen Strae it carries conspicuous pebbles. The Leven Schists are greenish-grey mica-schists (or phyllites) with a marked tendency to lamination. They are often somewhat garnetiferous, and in the districts of Glen Spean and Glen Etive they are rich in pseudomorphs after actinolite. A feature of the group is the Banded Series, which connects the more pelitic portions with the Glen-Coe Quartzite; in this Banded Series, quartzose beds are very common, while black graphitic seams and calcareous lenticles are generally to be found. The Banded Series is, as a rule, subordinate in bulk; but it assumes immense proportions about the head of Loch Creran, and thence north-eastwards towards Loch Etive.

Ballachulish Limestone, of which there are two main subdivisions—(1) bands of cream-coloured limestone at the margin of the Leven Schists followed by pale-grey, more or less calcareous mica-schist, often highly quartzose, and (2) a dark-grey or black, relatively pure limestone at the margin of the Ballachulish Slates.

Ballachulish black graphitic and pyritous Slates.

Appin Striped Transition Series.

Appin Pebbly Quartzite.

Appin, cream-coloured, pink or dark-striped, dolomitic Limestone; sometimes in two well-marked subdivisions separated by flaggy quartzite and phyllite.

Appin grey Phyllites (or Mica-Schists), often with a large proportion of flaggy quartzite.

Cuil-Bay black graphitic Slates.

Original order of deposition.—The local evidence of relative age is much less conclusive in the Ballappel Foundation than in the preceding cases. I venture, however, to suggest that the order of statement in the previous section, with Eilde Flags at the top and Cuil-Bay Slates at the bottom, corresponds with the original order of deposition. My reasons are as follows:— cf Bailey G.M. 1930 Vol. 67. pp7

(1) Stratigraphical correlation between the great structural subdivisions of the Highlands is at the present time tentative. Still, there is much to be said for the commonly accepted view that the Ballachulish Slates, Easdale Slates, and, in a broad sense, the Tayvallich Slates are on one and the same horizon (p. 106). If so, then, since the Easdale and Tayvallich Slates can both be shown to be younger than their associated pebbly quartzites, it follows that the Ballachulish Slates are younger than the Appin Quartzite.

(2) Such a belief is in accord with the interpretation of the best-known slides of the district as thrusts (p. 90).

(3) Such a belief leads also to the conclusion that the great recumbent folds of the Ballappel Foundation originated during south-eastward movement in conformity with the phenomenon that took place at higher levels, as evinced by the Ben-Lui and Carrick-Castle Folds.

Structure.—The stratigraphical characteristics of the Ballappel Foundation are wonderfully helpful. The groups are, for the greater part, both distinctive and constant. This renders mapping easy, and the reading of tectonic features correspondingly accurate and full. The more important results are as follows:—

(1) Great recumbent folds are characteristic of the district.[1] Two main examples, both of them closing south-eastwards, have been named the Ballachulish and Appin Folds respectively.

(2) The development of these great folds has been accompanied by very extensive sliding[2]: in any particular fold, slides are not necessarily restricted to one limb—they may occur in both; some of them are thrusts, some lags. The Ballachulish Slide, which occurs in the lower limb of the Ballachulish Fold, is interpreted by Mr. Macgregor and myself as having a displacement of more than 24 miles (1912 *b*, p. 174; the irreducible minimum is 9 miles, 1916, p. 83).

(3) The recumbent folds and associated slides have been subjected to extensive secondary folding, often thousands of feet deep and isoclinal in character. A pronounced example is the Glen-Creran Syncline (fig. 1, p. 84), which may be regarded as a partial northward continuation of the Loch-Awe Syncline; the Glen-Creran Syncline is separated from the Ben-Lawers Syncline by a comparatively gentle anticline named after Glen Orchy (1912 *b*).

Although slides of two kinds occur, it is reasonable to suppose that the dominant slides of the district are of the nature of thrusts, not lags. In my judgment the two most important slides are the Ballachulish and Fort-William Slides, which characterize the

[1] See also 1922, Report A, par. 5; Report B.

[2] *Ibid.* Report A, par. 5.

lower limbs of the Ballachulish and Appin Folds respectively. I venture, therefore, to class these two slides as thrusts, which means, of course, that the Ballachulish and Appin Folds are anticlines, and that their south-eastward close is an indication of south-eastward movement.

The identification of the Ballachulish and Fort-William Slides as thrusts opens the way for the entrance of 'nappe terminology.' That portion of the Ballappel Foundation which occurs above the Ballachulish Thrust may be assigned to the Ballachulish Nappe, and is coloured accordingly in Pl. I; the next great mass, bounded above and below by the Ballachulish and Fort-William Thrusts respectively, may be spoken of as the Appin Nappe.

A glance at Pl. I shows that the Ballachulish Nappe extends as a recognizable entity eastwards from Ballachulish to the limit of the district under consideration. Westwards between Loch Leven and Loch Creran it has been locally removed by transgression of the Iltay Nappe, which there rests directly upon the Appin Nappe. This latter is a very well-defined structural mass in the western part of the area, where it overlies a foundation consisting mainly of Eilde Flags (p. 94). South of the point where the Fort-William (Meal-a'-Bhuirich) Thrust is shown in Pl. I as losing itself in the Eilde Flags, the definiteness of the Appin Nappe fails. In this part of the district, the outcrops of the Sub-Eilde Complex serve as a valuable index to the general structure of the ground.

Suggested Stratigraphical Correlations.

My many years' experience of the rocks of the three great structural subdivisions of the South-West Highlands has impressed me as much with their contrasts as with their resemblances; the Eilde-Flag and Glen-Coe Quartzite facies belong to the Ballappel Foundation; the Ben-Ledi Grit facies to the Iltay Nappe; lavas and volcanic breccias are confined to the Loch-Awe Nappe.

The most marked resemblance is the recurrence in each district of a thick series of sediments in which the sequence is black slate, transition series, pebbly quartzite, limestone. The agreement, so far as black slates[1] are concerned, is closest between the Ballachulish Slates of the Ballappel Foundation and the Easdale Slates of the Iltay Nappe, both of them the seats of an important roofing-slate industry. The comparison of the transition zone is, on the other hand, more telling in the case of the Iltay and Loch-Awe Nappes, where a conglomeratic tendency very commonly shows itself in this position as characteristic of a mixed assemblage of black slate, black limestone, and quartzite. Some of the slate- and limestone-bands, as well as the quartzite, are charged

[1] It is an arguable point whether the Loch-Avich and Tayvallich Slates are not wholly included in the transition zone.

with pebbles of quartz and felspar, and where these are particularly big they are often accompanied by rock-fragments. In the main, these latter are strictly local in origin (slate, limestone, quartzite, and, in the Loch-Awe Nappe, lava); but nordmarkite and other foreign boulders have been found by H. Kynaston (1908 *b*, p. 31) and Dr. B. N. Peach (1911, p. 71) at two important localities in the Loch-Awe Nappe.

Dr. J. S. Flett (1911, p. 75) has shown that the foreign boulders of the Loch-na-Cille Conglomerate (Loch-Awe Nappe) agree in type with those occurring in the Portaskaig Conglomerate of the Iltay Nappe. This is a very significant fact, for it emphasizes what most Highland geologists consider a certainty, that much of the quartz and alkali-felspar of the Crinan Quartzite (Loch Awe) came from the same source as the similar material of the Islay Quartzite (Iltay). But the reader is warned against thinking that the nordmarkite-boulders afford evidence for correlating the definitely volcanic conglomerate of Loch-na-Cille with the definitely non-volcanic conglomerate of Portaskaig. The two are distinct, both in character and in associates. The difference of character depends mainly on the circumstance that at least 90 per cent. of the fragments included in the Loch-na-Cille Conglomerate are of lavaform rocks unknown in the Portaskaig Conglomerate. The contrast of associates will be understood from the following statement:—The Crinan and Islay Quartzites, viewed broadly, are in each case susceptible of twofold division: one part is fine or relatively fine in texture, the other coarse. The Loch-na-Cille Conglomerate lies on the coarse side of the Crinan Quartzite, in a position marked by constant recurrence of conspicuous quartz- and felspar-pebbles. The Portaskaig Conglomerate, on the other hand, lies on the fine-grained side of the Islay Quartzite.

Without elaborating the subject, I offer below a table of correlation. It is important to remember that age-sequences have been fixed by very convincing evidence in the Iltay and Loch-Awe Nappes, and by suggestive relationships in the Ballappel Foundation. This in itself adds to the weight of the proposed correlations:—

Loch Awe.	*Iltay.*	*Ballappel.*
	Ben-Lui Schists.	Leven Schists.
	Ben-Lawers Calc-Schists.	Ballachulish Limestone.
	Easdale Slates.	Ballachulish Slates.
Tayvallich Slates, Limestones, and Conglomerates.	Transition Zone.	Striped Series.
Crinan Quartzite.	Islay Quartzite.	Appin Quartzite.
Shira Limestone.	Portaskaig Conglomerate and Islay Limestone.	Appin Limestone and Phyllites, and Cuil-Bay Slates and (possibly) Lismore Limestone.
Ardrishaig Phyllites.	Mull-of-Oa Phyllites.	
Erins Quartzite.	Maol-an-Fhithich Quartzite.	

The inter-nappe correlations suggested above are treated in this part as an end in themselves. They are not employed as links in the chain of evidence supporting the general structural interpretation, except in so far as they add somewhat to the strength of the conclusion that the Ballappel succession is correctly stated in descending order of age on p. 104. I may add, perhaps, that a visit to Blair Atholl (Perthshire) in 1920 impressed me very strongly with the value of the correlations here suggested. One cannot well question that the Perthshire Quartzite as exposed in Ben-y-Glo belongs to the Islay Quartzite, and yet its associates remind me irresistibly of Appin Limestone and Phyllites (with a weak development of Portaskaig Conglomerate) followed by Cuil-Bay Slates and Islay Limestone. In the Ballachulish district the sequence ends with Cuil-Bay Slates—unless the tantalizingly isolated Lismore Limestone, restricted to island occurrences, be distinct from the Ballachulish Limestone with which it has been hitherto correlated.[1]

III. Critical Discussion of the District reaching from Ardmucknish to Ben Lui.

Having now clambered somewhat laboriously from the summit of the Loch-Awe Nappe across the Iltay Nappe right down to the Ballappel Foundation, the reader is in a position to turn round, as it were, and view with comprehension the outstanding features of the structural succession considered as a whole. Near Dalmally, the outcrops of the Loch-Awe Group and Eilde Flags approach unusually close, while whole assemblages, well known to intervene between these two farther north-west or south-east, as the case may be, are here entirely absent (fig. 5, p. 109). It is my present task to indicate how some of these discrepancies are attributable to recumbent folding[2] and others to thrusting, and in so doing to bring my long description to a close. Unfortunately, it will be impossible to avoid the introduction of considerable local detail, for much of the reasoning is based on hitherto-unrecorded field-observations.

Appin and Ballachulish Folds.

Since the Appin and Ballachulish Folds have been very fully described (1910 *a*; 1912 *b*; 1914; 1916), the following dogmatic statements regarding them must suffice:—

(1) The two folds close quite clearly south-eastwards.

(2) The groups enumerated in explanation of A & B, fig. 5, and with them the Ballachulish Limestone, do not continue far underground in the core of the Appin Fold. I once thought that a limestone exposed near Loch Dochard (12 miles south-east of Ballachulish) was probably the Ballachulish Limestone enclosed in the Appin Fold; but I now regard it as occupying a lower structural level (p. 94).

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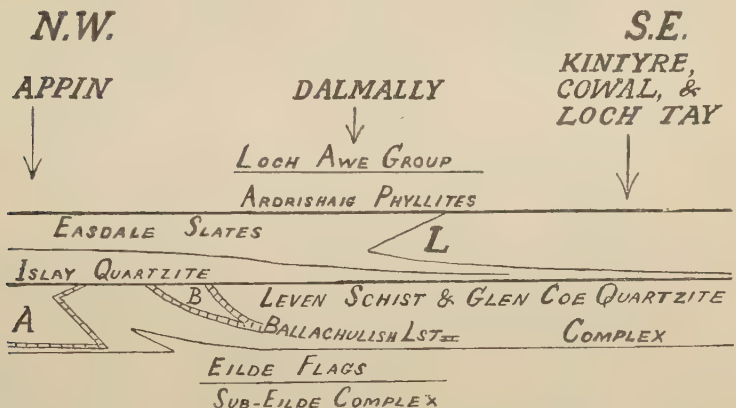
[1] It is coloured as Ballachulish Limestone in Pl. I.
[2] See also 1922, Report A, par. 6.

(3) Of the groups enumerated in explanation of A & B, the Cuil-Bay Slates are unrepresented in any exposure of the Ballachulish Fold; in the same fold the Appin Phyllites and Limestone do not extend into Glen Coe, and fail to reach more than about 2 miles east of the head of Loch Creran (1914, pl. xlv); the Appin Quartzite continues to Glen Coe, about a mile east of Ballachulish, and then stops; while near the head of Loch Creran it is found no farther east than the Appin Limestone; the Ballachulish Slates are still recognizable, some 10 feet thick, in Coire Mhorair, half-a-dozen miles east of Ballachulish: they are, however, absent in the Windows of Etive, and near the head of Loch Creran are little more persistent than the associated Appin Quartzite, Limestone, and Phyllites.

(4) Admittedly, the limitations just outlined are rendered a little indefinite, owing to the part played by slides in the construction of the Appin and Ballachulish Folds. At the same time, I hold (and I do not think that anyone familiar with the evidence would disagree) that the Appin Quartzite and

Fig. 5.—*Diagrammatic section illustrating the geological contrasts north-west and south-east of Dalmally.*



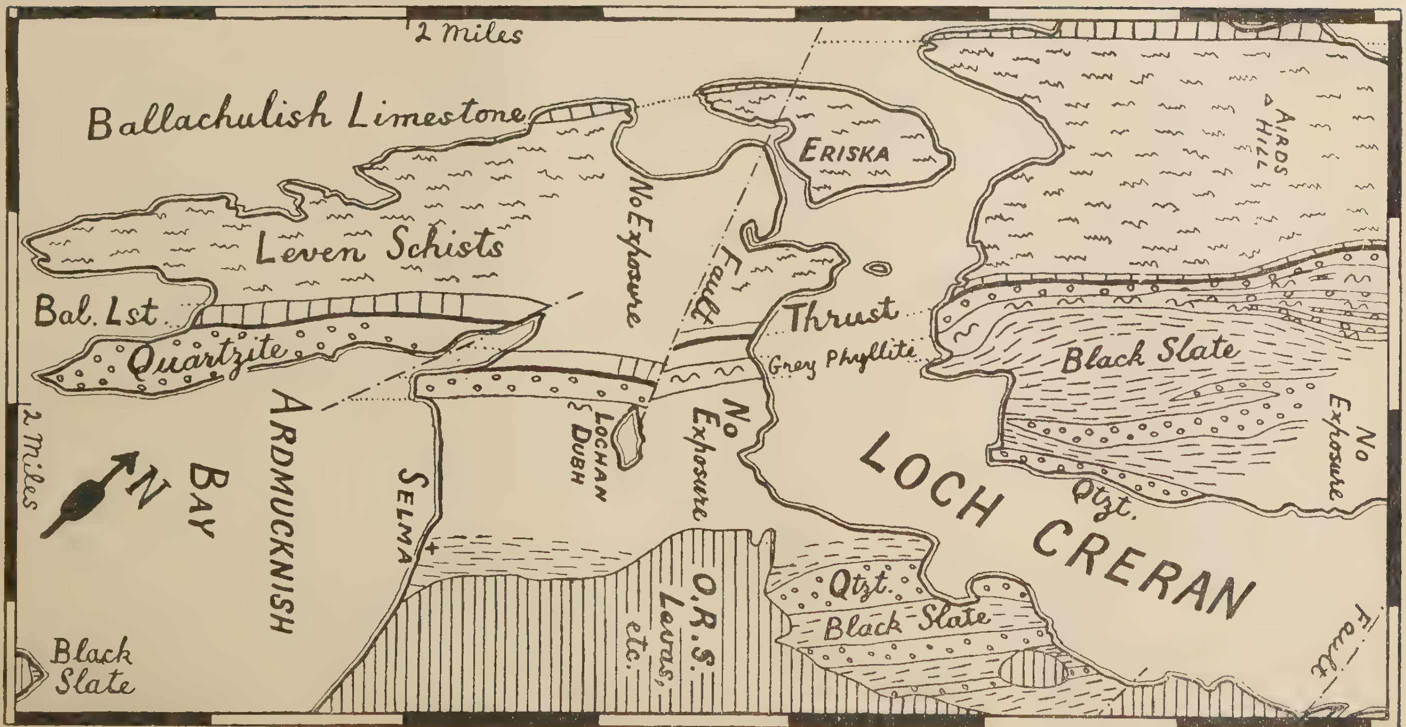
[A & B = Cores of the Appin and Ballachulish Folds constituted of Cuil-Bay Slates, Appin Phyllites, Appin Limestone, Appin Quartzite, and Ballachulish Slates.

L = Core of the Ben-Lui Fold, constituted of Ben-Lawers Schists, Ben-Lui Schists, Loch-Tay Limestone, Pitlochry Schists, Green Beds, Ben-Ledi Grits and Schists, Aberfoyle Slates, and Leny Grits.]

Ballachulish Slates do not extend south-east of the Windows of Etive in either the Appin or the Ballachulish Fold.

(5) The Ballachulish Nappe can be recognized with considerable confidence in the Dalmally district, where it has been interpreted as consisting of a great mass of Leven Schists overlying a tolerably constant remnant of Ballachulish Limestone. Mr. M. Macgregor and I have succeeded in tracing its outcrop from the south-eastern corner of the Etive Granite, right round the Glen-Orchy Anticline to Ben Doirean and beyond (1912 *b*, p. 172 & pl. x). The limestone rests, through the intervention of the Ballachulish Thrust, upon an attenuated representative of the Banded Series of the Leven Schists. The Banded Series in its turn rests on Glen-Coe Quartzite, very thick in the south and thin or absent in the north, and below this come Eilde Flags with local exposures of the Sub-Eilde Complex at Ben Udlaidh and (presumably) at Loch Dochard too.

Fig. 6.—*Geological map: Loch Creran and Ardmucknish Bay.*



Contact of the Ballappel Foundation and the Iltay Nappe at Loch Creran.

Several workers have attacked the difficult problems of Loch Creran at one time or another in the past—Symes, Grant Wilson, Kynaston, Peach, and myself. Looking back at our record of partial success and partial failure, I feel that the difficulties as they at first presented themselves were insurmountable—that, in fact, we were confronted with a geological redoubt that could not be expected to capitulate until the whole surrounding country had been subjugated. In the summer of 1919 I renewed the assault, and remapped on the 6-inch scale the critical portion of the district covered by fig. 6. I then found that the present state of our knowledge of the South-West Highlands afforded a simple solution of much that had been previously inexplicable.

The thrust shown as a thick black line in fig. 6 divides the district into two dissimilar portions. These will now be considered in some detail from north-west to south-east. First of all, it may be stated that the dip everywhere tends to be steep, while the more yielding rocks show very obvious corrugations.

The Ballappel Foundation, north-west of the Thrust.—Three lithological belts have been mapped, succeeding one another from north-west to south-east as follows:—

(1) Limestone, never fully exposed, owing to limitation on the north-west by sea or raised beach. Four good exposures occur: the northernmost on the shore west of Airds Hill; the next on the eastern shore of Airds Bay; the next on the western shore of Eriska; and the southernmost on the shore at Ardentinny. The northernmost exposure is the fullest, and measures some 200 yards across the strike. It reads as follows from north-west to south-east:—Dark-grey highly-calcareous slates, with thin grey limestone-seams; dark-grey slates; sandy-grey limestone weathering brown, except that some of the purer bands weather grey; thick, white, sandy, thinly-bedded limestone weathering brown; passage to grey phyllite, which at first has white limy streaks.

(2) Phyllite, constituting a belt rather more than a mile wide, and well seen in coastal and inland exposures. The deposit is predominantly greenish-grey, and is in part laminated, in part homogeneous. As very subordinate characteristics of the belt, one may note the occasional occurrence of slightly calcareous bands, isolated layers of quartzite, and also seams of dark phyllite.

(3) Limestone.—The best exposures from north to south are:—At the northern edge of fig. 6, beside a hill-track 500 yards south-south-east of Strathappin Farm—ochreous-weathering calcareous phyllites, with a band of sandy white limestone; 400 yards north-north-west of Ledgrianoch Farm and about 50 yards east of the high road—buff-weathering phyllitic limestone seen for 20 yards across the strike; beside the path east of Ledgrianoch—ochreous-weathering calcareous phyllites (and here I may say that these three very important exposures north of Loch Creran might very easily have been overlooked, and that we owe their discovery entirely to Grant Wilson). East of the road and west of Lochan Dubh—pale phyllitic limestone; and, lastly, a series of exposures, a mile and a half long and 100 yards broad, leading to the coast at Camas an Fhais—very calcareous phyllites with white or yellowish limestone-beds, and (on the shore) a few feet of black slate and black limestone on the south-east side of the outcrop.

The claim that these three lithological belts belong to the Ballappel Foundation is easily vindicated. The limestone (1) is the southern continuation of the Ballachulish Limestone, which, in the upper limb of the Appin Fold, continues north-eastwards beyond the limits of fig. 6 for more than 30 miles. As has been already stated, the exposure of the limestone within the area covered by fig. 6 is incomplete; it is on this account that one cannot point to a purer black portion of the belt, but what is seen is thoroughly typical in character. Its associates on both sides—the gap in the section on the north-west side is not extensive—tell exactly the same tale. Of these associates the phyllite (2) on the south-east is manifestly the southern continuation of the western part of the type-outcrop of Leven Schists. It presents no noteworthy change of character, except a decrease in metamorphism (fig. 3), and this difference traced on the ground is found to make its appearance quite gradually. Finally, the limestone (3) must be regarded as a folded reappearance of the Ballachulish Limestone. It reproduces exactly the characters which are found in the limestone (1) with this addition that, in the southern coast-section (Camas an Fhais), it shows what may be regarded as a beginning of the pure black portion of the group.

The Thrust.—The heavy black line of fig. 6 stands for a thrust. The local evidence points clearly to a dislocation of first-class importance, and this evidence I shall now consider under two headings:—

(1) In the first place, the succession of the Ballappel Foundation, as exemplified close at hand in the core of the Appin Fold or at the head of Loch Creran in the core of the Ballachulish Fold (1914; 1916, p. 51), would lead us to expect one of two things on crossing the south-eastern limestone belt: either a return to Leven Schists or, failing this, a continuance into the black part of the Ballachulish Limestone followed by Ballachulish Slates. Instead, one steps abruptly on to a quartzite, which in the south is of imposing dimensions.

(2) Two exposures of the junction of the limestone with the unexpected quartzite can be closely examined. One occurs west of Lochan Dubh,[1] the other on the shore at Camas an Fhais. In both cases the ocular evidence of movement is very striking indeed. The junction is definitely transgressive, and the shearing is extreme.

It will be noted that the evidence afforded by (1) is much more serviceable in many ways than that derived from (2): (1) implicates the whole line of contact as traced in fig. 6 for half-a-dozen miles; whereas (2), considered by itself, might be interpreted as of very local significance. That the dislocation, where well exposed, is definitely betrayed by an appearance of excessive shearing is due in large measure, I think, to the very low grade of metamorphism of this particular district (fig. 3).

Iltay Nappe south-east of the Thrust.—The series of

[1] See also 1922, Report A, par. 9.

rock-belts ushered in by the quartzite just mentioned present themselves in the following order:—

(1) Quartzite, forming a continuous belt which is easily traced, about 100 yards broad in its northern exposures, and 500 yards broad, where, in Garbh Ard, it finally goes out to sea. It is essentially fine-grained (in fact, pebbles are very rare indeed), thinly bedded, and white.

(2) Greenish-grey Phyllite with dark seams. In the north the outcrop is 600 yards wide, but is interrupted by four or five bands of quartzite, with sufficiently broad outcrops to be shown on a 6-inch map; they are probably folded repetitions of (1). Southwards the phyllite outcrop is unbroken, and is only 100 or 200 yards wide. A good exposure is afforded on the northern shore of Loch Creran, and another in a ridge, a little south of this loch, at Baracaldine Castle. The phyllite is last seen succeeding the Garbh-Ard Quartzite (1) south-west of Lochan Dubh.

(3) Black Slates followed by a mixed assemblage of Black Slate, Quartzite, and subordinate Limestone.

The succession grouped under (3) can be studied in shore-sections on the north side of Loch Creran (3 *a*), or south of the loch eastwards from Rudha Garbh (3 *b*), or, again, at Selma on Ardmucknish Bay (3 *c*):—

(3 *a*) North of Loch Creran, jet-black graphitic slates, rich in pyrites, give place south-eastwards to black slates varied by the incoming of quartzite-bands, some of them pebbly; but, for about 1000 yards, these quartzite intercalations are quite subordinate. Then follows a belt of predominant quartzite, forming a fairly prominent ridge. Where examined, the quartzite of the ridge proved to be well bedded and associated with thin partings of black slate. Pebbles were noted in some of its bands. Perhaps this quartzite has a discontinuous outcrop pitching up into the air without actually reaching the shore; but the exposures leave this in doubt. Beyond a gap in the coast-section (which appears to correspond to black slate with occasional pebbly beds seen a little inland) fairly definite quartzite is once again encountered, constituting the headland at the turn of the loch and also the north-eastward trending coast for a mile beyond. The quartzite in these excellent shore-exposures carries intercalations of dark and black slates, as well as of more or less sandy, pale-grey, dark-grey, and black limestones. All three rock-types (quartzite, slate, and limestone) are often seen to be pebbly with large grains of blue and white quartz and felspar, and one of the limestone-beds carries in addition small pellets of penecontemporaneous sediment.

(3 *b*) The exposures south of the loch, east from Rudha Garbh, are too similar to those just described on the opposite shore to deserve detailed description. At Rudha Garbh, black slate predominates, pyritous as usual, and associated with subordinate quartzite and black limestone. This belt is followed eastwards by a succession of outcrops in which the mastery lies sometimes with quartzite, sometimes with black slate; while dark limestone is in either case a subordinate, though characteristic, associate. The quartzite is generally fine in texture, but occasionally pebbly with grains of blue and white quartz and also felspar; and some of the dark slaty bands carry similar pebbles. This alternation continues until slaty-grey phyllite takes its place about 100 yards west of a fault introducing lavas of Old Red Sandstone age into the shore-section.

(3 *c*) The Selma exposures on Ardmucknish Bay recall those of Rudha Garbh, with its black slate, limestone, and quartzose beds; the section is chiefly noteworthy for a cleaved breccia, which Dr. J. S. Flett has given good reason to believe may be a crush-conglomerate (1908 *b*, p. 58).

The assemblage of interbedded black slate and quartzite just described is referred to the Iltay Nappe for two reasons:—

(1) Character.—This mixed assemblage, except that it does not appear to contain a definitely conglomeratic horizon, almost exactly reproduces the Scarba development of the Transition Group connecting the Islay Quartzite and Easdale Slates. Only two other groups need be mentioned as possible rivals, namely, the Tayvallich Slates of the Loch-Awe Group (Loch-Awe Nappe), and the Striped Series connecting the Appin Quartzite with the Ballachulish Slates (Ballappel Foundation). Of the Tayvallich Slates it may be said that not only are they more conglomeratic than the Creran rocks, but also they are richer in limestone, while everywhere they are accompanied by volcanic rocks. Of the Striped Series, that it presents a more definitely continuous interbanding of quartzite and slate; while its limestones, in my experience, never carry pebbles.

It will be noticed that the correlation here advanced refers the Garbh-Ard Quartzite to the Islay position. Now, in Islay, Jura, and Scarba, and eastwards to Ben Vrackie in Perthshire, the part of the quartzite bordering the Transition Group is distinctly pebbly, whereas in Garbh Ard it is fine-grained. Possibly this betokens a local facies, or possibly it indicates a mechanical omission of the pebbly division from the Garbh-Ard outcrop.

(2) Position.—Island and mainland exposures show that a belt of Easdale Slates of persistent character reaches north-north-eastwards from Luing, through Oban, to the mouth of Loch Etive. The slates are constantly emerging from under a cover of Old Red Sandstone sediments and lavas. Their larger outcrops are shown in Pl. I, while the position of several smaller inliers will be found in a text-figure of the forthcoming Geological Survey Memoir dealing with the 1-inch Map, Sheet 44.

At Oban, where the Easdale-Slate belt is fully 5 miles wide, the sea hides the probable continuation of both the Transition Group and the Islay Quartzite. The first schists seen beyond the gap (in Mull, Lismore, and neighbouring islets) belong quite definitely to the Appin Fold of the Ballappel Foundation. Accordingly, it is between the Easdale Slates at the mouth of Loch Etive and the exposure of the Appin Fold in the western part of Ardmucknish that one would naturally expect the Transition Group and Islay Quartzite to reach the mainland. The absence of other members of the Islay succession, as, for instance, the Portaskaig Conglomerate and Islay Limestone, is readily attributable to the obvious dislocation which brings the Garbh-Ard Quartzite into conjunction with the Ballachulish Limestone (fig. 6, p. 110).

The evidence of position forbids the reference of the Ardmucknish-Creran rocks to the Tayvallich Group of the Loch-Awe Nappe. The Kilbride Inlier, east of Oban (Pl. I), almost certainly indicates a northward extension of the Craignish belt of Ardrishaig Phyllites, beneath Old Red Sandstone lavas, on its way to link up with the Pass-of-Brander exposures, where the same phyllitic group extends continuously from Loch Etive to Loch Awe, and so to Loch Fyne and Ardrishaig. Dr. B. N. Peach has described the Kilbride Inlier as probably in part Easdale Slates, in part Ardrishaig Phyllites (1908 *b*, p. 38). I could find nothing in it that did not seem definitely of Ardrishaig type—but such a difference of opinion is, of course, of quite secondary importance in this particular connexion.

The evidence of position, if one were restricted to the Loch-Creran district, would, on the other hand, seem to favour a correlation of the Iltay Nappe with the Ballachulish Nappe, since little,

if anything, occurs between the Appin and Iltay Nappes in Ardmucknish. The alternative (illustrated in fig. 5, p. 109) is that the Iltay Nappe has almost or quite pushed aside the Ballachulish Nappe in the Ardmucknish district; but the evidence for this interpretation is reserved for the following section, where it will be shown that black slate and pebbly quartzite of the Iltay Nappe have a south-eastward extension quite out of keeping with the recognized limitations of such rocks in the Ballachulish Nappe.

In the foregoing argument no attention has been paid to a very confusing feature of Loch-Creran geology. An important fault, known as the Strath-Appin or Pass-of-Brander Fault, crosses the loch at the eastern corner of fig. 6. Its downthrow is to the south-west, as shown by its effect on the distribution of the Old Red Sandstone lavas. Along its course, west of the loch, rock-exposures are altogether wanting in a belt upwards of half a mile wide. North of this obscure tract, they occur again in their usual profusion, but they can be shown to belong almost entirely to the Leven-Schist Group of the Ballappel Foundation. The contrast of character is, however, not nearly so marked as might be desired. The Banded Series of the Leven Schists (p. 104) is very strongly developed beneath the Ballachulish Nappe between the Ballachulish Granite and Loch Etive, and is for several miles well seen about the head of Loch Creran. A prevalent rock-type is a grey quartzose schist, passing gradually into non-pebbly impure quartzite, with repeated laminations of black seams.

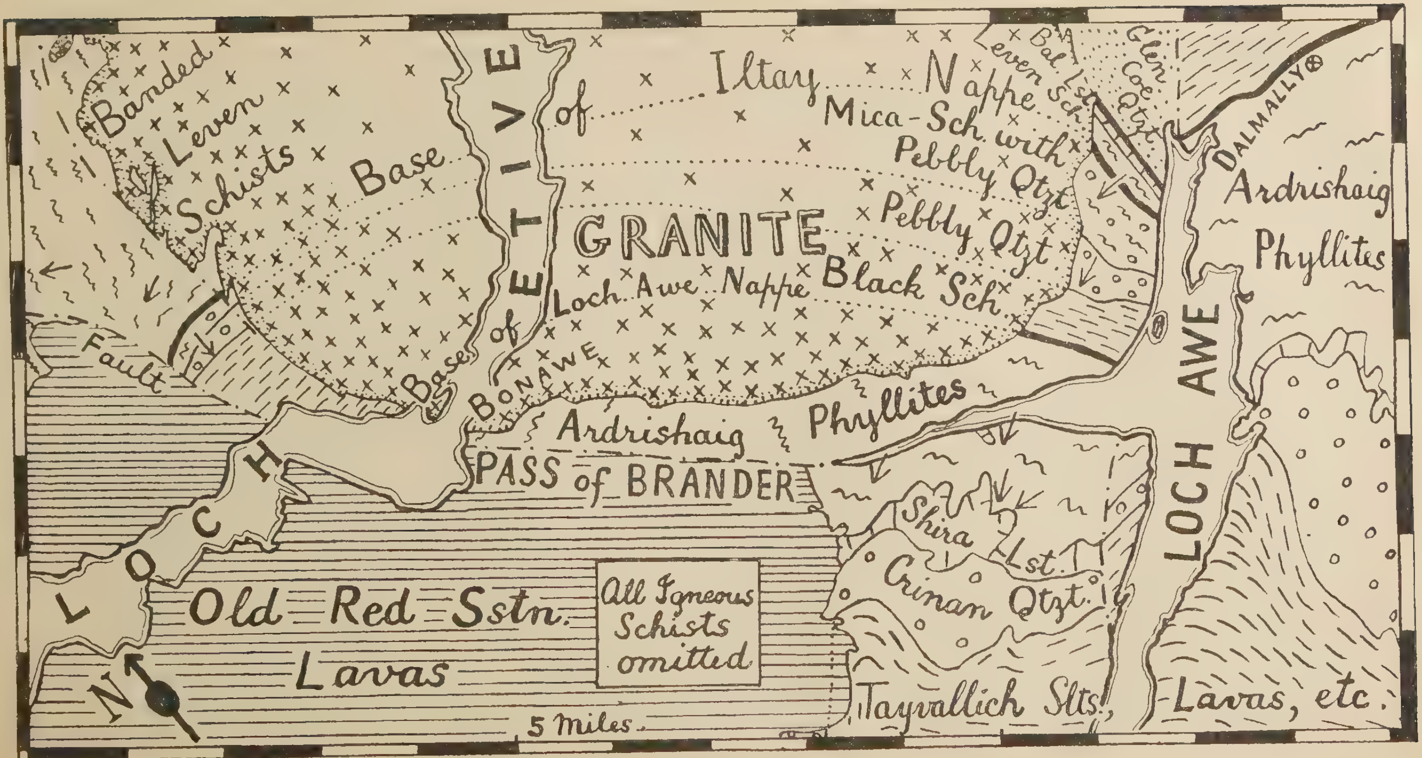
It is not surprising that at first this Banded Series was supposed to belong to the same stratigraphical group as the rocks south of the fault, now referred to the Transition Group of the Iltay Succession. The reasons which render such a correlation untenable at the present time are:—

(1) The frequent pebbly character, the limestone-bands, and the genuine black slates of the Transition Group are wanting in the Banded Series—a contrast which impressed Clough strongly when in conversation he disagreed with the correlation of the two accepted by Peach, Horne, Grant Wilson, and myself, during a joint traverse in 1906.

(2) At the time when we made our joint traverse, Grant Wilson was of opinion that the Banded Series at the head of Loch Creran was merely a local facies of the Ballachulish Slates. It therefore appeared that, to correlate the Transition and Banded Series of Loch Creran, was simply equivalent to correlating the Easdale and Ballachulish Slates—a probable enough correlation even to-day (p. 106). When later it was shown that the Ballachulish Slates continue with constant character to the head of Loch Creran, and that the Banded Series belong to the Leven Schists, the whole situation changed. A correlation of the Transition and Banded Series of Loch Creran now involves a correlation of Easdale Slates and Leven Schists within the limits of a single nappe; and this, with its attendant stratigraphical consequences, seems incredible.

(3) When we made our correlation, we thought that the outcrop of the Transition Series gave place *in toto* to that of the Banded Series. I am now in a position to show (next section) that the pebbly-quartzite and black-slate series preserves its individuality in an outcrop which escapes eastwards round the northern end of the Loch-Awe Syncline.

Fig. 7.—*Geological map: Loch Etive, Pass of Brander, and Loch Awe.*



One last point deserves notice before we turn eastwards from Loch Creran. Inspection of Pl. I shows a very limited discontinuous outcrop of the Iltay Nappe between the Strath-Appin Fault and the Ballachulish Granite. Narrow exposures of massive white quartzite (pebbly in the south with quartz and felspar, and fine-grained in the north) have been met with intermittently along one particular line of strike. They probably represent little klippen of the Garbh-Ard (Islay) Quartzite. They lie within the belt of Banded Series, if this term be used in its broadest sense; but for a mile on the south-east side grey phyllite is the prevalent rock of the district.

Outcrop of the Iltay Nappe north of the Loch-Awe Nappe.

It is here proposed to trace the outcrop of the Iltay Nappe in its eastward course between Loch Etive and Loch Awe, and onwards past Dalmally into Perthshire.[1] The only part of this description that is definitely new refers to the discontinuous portion of the outcrop included within the contact-aureole of the Etive Granite (fig. 7).

Ballappel Foundation and Iltay Nappe, north-west of the Loch-Awe Nappe.—North-east of the Pass-of-Brander, or Strath-Appin, Fault there is an imposing display of the Banded Series of the Leven Schists all the way from Loch Creran to within about a mile of Loch Etive. Grey phyllitic material (notably hornfelsed, and displaying pitted surfaces indicative of cordierite wherever it comes within a mile of the Etive Granite) is associated with perhaps preponderant fine-grained, grey, quartzose schists, often interlaminated with dark seams.

From our detailed knowledge of the geology of the head of Loch Creran (1914; 1916, p. 51), the whole of this tract can be referred with confidence to that portion of the Ballappel Foundation which immediately underlies the Ballachulish Nappe. There is no very marked change until, east of the angle of the River Esragan, a massive pebbly quartzite figures prominently in the crags of the hillside, 2 miles in from the left-hand margin of fig. 7. The quartzite dips steeply, and its outcrop measures 300 yards across the strike. As seen in the crags it is but little sheared, and contains subangular pebbles, often half an inch long, consisting of quartz and subordinate felspar; some of the quartz is blue.

Although the incoming of quartzite in bulk is abrupt, examination reveals the presence of minor pebbly quartzite-bands in the banded quartzopelitic hornfels (pitted with cordierite) within a zone about 400 yards wide bordering the quartzite on its northern side. This belt of interbedded phyllite and pebbly quartzite I have seen at intervals at the margin of the pebbly quartzite far into Perthshire, where it is conspicuously displayed, for instance, in the Pass of Killiecrankie. The Perthshire sections which

[1] See also 1922, Report A, par. 8.

I studied in 1920 seem to establish the identity of the Killiecrankie Group with the flag group strongly developed in Northern Jura and Scarba (1917, p. 152) within the limits of the Islay Quartzite.

On the southern side of the pebbly quartzite, interbedded quartzite and black slate-hornfels continue for some distance, until towards Loch Etive they give place to black slate. This latter, scarcely indurated at all, is seen at the bridge at Inveresragan, and in baked condition in the Blarcreen Burn. Between the Blarcreen Burn and Bonawe Ferry there are many roadside exposures of hornfelsed black slate with a considerable proportion of quartzose stripes. I first saw the Inveresragan exposures of black slate in 1914 exactly where I hoped to find them from my knowledge of the Dalmally sections (to be described presently). In 1919 I was able to return to the subject, and was rewarded by the discovery of the pebbly quartzite. I have no doubt, on the score of character and position, that this pebbly-quartzite and black-slate assemblage represents the eastward continuation of some part of the Islay Quartzite, Transition Group, and Easdale Slates, as represented in the Loch-Creran and Oban districts.

Loch-Awe Nappe.—In Eilean Duirinnis, immediately north of Bonawe Ferry, banded calcareous hornfels occurs at the edge of the Etive Granite. On the other side of the ferry, continuing for a distance of 6 miles, similar calcareous hornfels constitutes the strip of country between the Pass-of-Brander Fault and the Etive Granite. The calcareous laminæ are mainly represented by malacolite, colourless garnet, epidote, and tremolite. An excellent petrographical account has been given by Sir Jethro Teall (1908 *b*, p. 141). Near the eastern limit of the outcrop, metamorphosed limestone is more than usually prominent.

I have examined this Pass-of-Brander outcrop several times, and heartily concur with H. Kynaston's reference of it to the Ardrishaig Phyllites. The reasons for placing the Ardrishaig Phyllites as a whole in the Loch-Awe, rather than in the Iltay Nappe, will be discussed later (p. 121).

Ballappel Foundation and Iltay Nappe, north-east of the Loch-Awe Nappe.—When Mr. Macgregor and I described the geology of the Glen-Orchy Anticline before this Society, we traced a thick structural succession above the Ben-Udlaidh outcrop of the Sub-Eilde Complex (1912 *b*, p. 172). At that time we did not speak of the Ballachulish Slide as a thrust, and accordingly did not use the term nappe; otherwise, the ensuing sequence is little more than a repetition of our published conclusions:—

Black pelitic schist.
Pebbly quartzite.
Interbedded grey pelitic schists and pebbly quartzite.

Ballachulish Nappe { Thick grey pelitic schist—Leven Schists.
Thin, fairly persistent limestone—remnant of Ballachulish Limestone. }

Ballachulish Thrust.

Banded pelitic schists and quartzite—remnant of Leven Schists.

Quartzite, locally very thick—Glen-Coe Quartzite.

Gneissose flagstones—Eilde Flags.

Of these rocks, everything below the interbedded pelitic schists and pebbly quartzite is referable to the Ballappel Foundation. The remainder is obviously the interrupted continuation of the similar association cropping out west of the Etive Granite, and already correlated (p. 118) with some portion of the Islay Quartzite, Transition Group, and Easdale Slates. The agreement will perhaps be better appreciated after reading the following detailed description :—

Near the south-east of the granite, one passes north-eastwards from the Ardrishaig-Phyllite outcrop on to a belt of black slate-hornfels about 700 yards wide. Graphitic layers and streaks are abundant, and rusty weathering due to pyrites is characteristic. At the same time quartzose material is well represented, locally giving rise to a band of quartzite.

Beyond the black slate, one encounters an equal breadth of quartzite, which, though somewhat impure, is everywhere markedly pebbly, and but little split by partings. Beyond this main quartzite, one meets with grey pelitic hornfels in which for 800 yards bands of pebbly quartzite continue as a minor feature.

The black slate mentioned above as succeeding the Ardrishaig Phyllites is not so prominent in this section as it is west of the Etive Granite, but this defect is made up in the Dalmally exposures east of the Glen-Strae Fault, where a very big development of black schist with subordinate limestone occurs. Mr. J. B. Hill has rightly emphasized the manner in which these black schists are for the greater part interposed between the Ardrishaig Phyllites on the south, and the pebbly quartzite on the north (1908 *b*, p. 28), although the latter has its outcrop broken to some extent by bands of black schist. Various conclusions follow from the evidence adduced in the present and preceding sections :—

(1) A pebbly-quartzite and black-slate assemblage has been traced north-eastwards from the Islay Archipelago to Loch Creran and thence eastwards to Dalmally and the Ben-Doirean Range.[1] This, with the grey pelitic group carrying the interbedded pebbly quartzite, will be termed for brevity the Islay-Easdale Assemblage; its outcrop is clearly shown in Pl. I.

(2) On the inside of the curved outcrop of the Islay-Easdale Assemblage lie the Ardrishaig Phyllites of the Loch-Awe Nappe; on the outside, a varied succession depending on locality.

(3) There is abundant evidence that the Islay-Easdale Assemblage underlies the Loch-Awe Nappe and overlies the rock-groups appearing along its outer margin. This evidence may be considered under the headings 3 *a*–3 *c*.[2]

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[1] See also 1922, Report A, par. 8.

[2] *Ibid.* compare (3 *a*) & (3 *c*) with Report A, par. 4.

(3 *a*) The detailed downward succession from the centre of the Loch-Awe Syncline through the various subdivisions of the Loch-Awe Group to the Ardrishaig Phyllites has already been traced (p. 97). The conformity of outcrop of the Islay-Easdale Assemblage shows that this assemblage must in its turn underlie the Ardrishaig Phyllites. It has already been pointed out that the general east-and-west outcrop of the Ardrishaig Phyllites near the northern end of Loch Awe is due to pitch. The significance of the sympathetic east-and-west deflection of the Islay-Easdale outcrop is unmistakable.

(3 *b*) Local evidence (1917) shows quite as clearly that the Portaskaig Conglomerate, Islay Limestones, Mull-of-Oa Phyllites, and Maol-an-Fhithich Quartzite, as exposed in the Islay Anticline, structurally underlie the Islay-Easdale Assemblage here considered.

(3 *c*) Local evidence further shows that, in the Glen-Orchy Anticline, (pp. 118 & 124) a descending structural sequence can be traced which leads from the Islay-Easdale Assemblage right down to the Sub-Eilde Complex as exposed in the Beinn-Udlaidh Fold.

(4) It follows, then, that the Islay-Easdale Assemblage overlies that part of the Ballappel Foundation with which it comes into contact in the Loch-Creran district.

(5) Accordingly, if for no other reason, the Islay Quartzite cannot be interpreted as a special facies of the Glen-Coe Quartzite in normal contact with the Banded Leven Schists of the Loch-Creran district. The Glen-Coe Quartzite, which is seen in normal contact with the Banded Leven Schists at the head of Loch Creran and in the Windows of Etive, could only reappear in the district of Lower Loch Creran by emergence from below the adjacent Leven Schists.

(6) The Islay-Easdale Assemblage is also, for two good independent reasons (6 *a* & 6 *b*), distinguishable from the Appin Quartzite and Easdale Slates of the Ballachulish Fold:—

(6 *a*) The Islay-Easdale Assemblage has been traced into the Ben-Doirean Range 15 miles south-east of the Windows of Etive, whereas the Appin Quartzite and Ballachulish Slates of the Ballachulish Nappe do not reach so far south-eastwards as these Windows (p. 109).

(6 *b*) The Islay-Easdale Assemblage overlies what are, with very high probability, regarded as the Leven Schists of the Ballachulish Nappe in the whole of the Glen-Orchy district (pp. 118 & 119).

(7) It must be admitted that the Islay-Easdale Assemblage is transgressive in its relationships. Otherwise, one would not find it in Ardmucknish resting upon the Appin Nappe, where one would naturally expect to meet with the Ballachulish Nappe (this statement holds substantially, even though the eastern limestone of Ardmucknish be regarded as a remnant of the Ballachulish Nappe, as it well may be).

(8) As the transgression obviously does not antedate the movement which gave rise to the Ballachulish Nappe, it seems necessary to regard it as mechanical, not stratigraphical, in origin.

(9) The conspicuous shear-zone separating the Islay Quartzite and the Ballachulish Limestone in the Ardmucknish Peninsula has been discussed (p. 112). Another interesting case of special shearing near the base of the quartzite has been noticed in stream-sections entering Glen Orchy from the east. There are intrusions of basic igneous rock in quartzose schist (probably Killiecrankie Group) in this position, and the two have been sheared and rodded in a most remarkable manner, with a resultant inter-banding of films, in certain cases no thicker than tissue-paper.

(10) The absence of the Portaskaig Conglomerate and Islay Limestone in the mainland exposures can be very readily attributed to the thrust invoked above on other grounds. The non-occurrence of these characteristic zones is, of course, merely local, since they reappear farther north-east in Schiehallion.

Ben-Lui Fold and the Thrust at the Base of the Loch-Awe Nappe.[1]

Before discussing the Ben-Lui Fold, I wish to express my indebtedness to Mr. J. B. Hill and to the late H. Kynaston for their mapping of that part of the district which, in fig. 8 (p. 122) lies south of the outcrop of the quartzite of the Iltay Nappe. The more northerly portion of fig. 8 is taken, practically as it stands, from pl. x of the account given by Mr. Macgregor and myself (1912 *b*); but the southern two-thirds of the map are based, with trifling changes, on Hill & Kynaston's work published in Sheets 45 & 46 of the Geological Survey 1-inch map. At the same time, it should be clearly understood that I alone am responsible for two important matters of interpretation expressed in the southern part of fig. 8: one, the distinction of the Ben-Lawers Schist from the Ardrishaig Phyllites; the other, the recognition of the thrust-plane at the base of the Loch-Awe Nappe.

In 1891, Mr. Hill traced the Ben-Lawers and Ardrishaig Groups into contact with one another in the neighbourhood of Ben Lui, and thus, it was thought, established their stratigraphical identity (1892 *b*, p. 385). The correlation is, of course, supported by a close general lithological resemblance of the two groups; but there has always been a difficulty: the Ben-Lawers-Ardrishaig Complex, considered as a unit, has three persistently different margins. The successions outwards from this complex are as follows:—

(1) Easdale Black Slates, leading on to Islay Quartzite; the local evidence points to the slates as later than the quartzite (p. 101).

(2) Crinan (Loch-Awe) Quartzite, approached through Shira Limestone, and followed by Tayvallich Black Slates, Limestones, and Lavas; the local evidence points to the slates as later than the quartzite (p. 97).

(3) Ben-Lui Garnetiferous Mica-Schist, succeeded by Loch-Tay Limestone; the local evidence points to the limestone as later than the schist (p. 101).

Exposures are far from continuous, but it seems certain that each of the three successions holds true for more than 50 miles along curving lines of outcrop. Manifestly normal faulting cannot be the explanation. In fact, only two alternatives are feasible: the first is to interpret the successions (1) & (2) as in some sense equivalent; the second to admit that extensive fold-faulting (or sliding, to use the shorter term) has been the determining factor of the triple margin. Three independent reasons (A–C) for adopting the second of these two alternatives are outlined below:—

(A) Succession (1) cannot be directly equivalent to Succession (2), since in (1) the rock-groups met with on leaving the margin of the Ardrishaig Phyllites are increasingly old, while in (2) they are increasingly young. This age-relation—coupled with the fact that the lithology of succession (3) is admittedly too dissimilar to be correlated with either (1) or (2)—obviously demands a slide. At the same time, age-relations are notoriously difficult to establish in unfossiliferous rocks, and therefore it is well that other evidence is available.

[1] See also 1922, Report A, pars. 5 & 7; Report B.

Fig. 8.—*Geological map: Glen Orchy and Ben Lui.*

(B) When the problem was approached by the Geological Survey, it was with the preconception that the Ben-Lui Schists were older than the Ben Lawers-Ardrishaig Complex, which latter was readily accepted as a stratigraphical unit. Moreover, large-scale slides were not at that time recognized as a phenomenon of the Southern Highlands. Accordingly, both the successions (1) & (2) were interpreted as of later date than the Ben Lawers-Ardrishaig Complex, and, in a general sense, as equivalent the one to the other. As regards details, the Islay and Crinan Quartzites were correlated, and local erosion was invoked to account for the continuous absence of Easdale Slates at the junction of the Crinan Quartzite and the Ardrishaig Phyllites. An attempt was also made to minimize the importance of the contrast of (1) & (2) by pointing to the Tayvallich Slates as widespread relics of the Easdale Slates. It is true that the Tayvallich Slates do not occur at the Crinan-Ardrishaig junction; but in the initial stages of the enquiry it was easy to postulate underground continuations of Ardrishaig Phyllites forming unexposed cores to imaginary anticlines wherever black slate showed itself in the quartzite area; also, it must be admitted, Dr. B. N. Peach mistook Loch-Avich Slates (1913 *b*, p. 290) for Ardrishaig Phyllites. In course of time, it has become apparent both to Dr. Peach and to myself that the Crinan Quartzite structurally intervenes between the Ardrishaig Phyllites, below, and the Tayvallich Slates, above (1911, Chap. v; for Mr. Hill's criticism of this change of front, see 1911, p. 61; 1913 *b*, p. 306). The progress of research has thus tended to emphasize the lithological dissimilarities of the successions (1) & (2).

But the reader may well ask whether the magnitude of the folding does not in itself afford a sufficient explanation. As pointed out already, the Easdale-Islay succession completely underlies the Ardrishaig Phyllites, while the Crinan-Tayvallich succession completely overlies the same. Accordingly, a correlation of the Easdale-Islay and Crinan-Tayvallich successions involves a recumbent fold with a core of Ardrishaig Phyllites not less than 20 miles in length, and, with so large a fold, a marked difference of facies might well be expected in the lower and upper limbs respectively. It is, however, unnecessary to develop this anticipated criticism, since it will be shown in the succeeding paragraph that the particular large-scale fold here contemplated is flatly contradicted by the local evidence.

(C) Fig. 8 illustrates the type-area for the union of the Ben-Lawers and Ardrishaig outcrops. It also shows clearly that the Ardrishaig Phyllites, where they extend westwards between the Islay-Easdale and Loch-Awe Assemblages, cannot be interpreted as a 20-mile fold-core. So massive and extensive a fold would have a recognizable core of Ben-Lui Schists for some part of its course, and such assuredly does not exist. The weight of this negative evidence will be better appreciated on consideration of the Ben-Lui Fold close at hand. Here, Ben-Lawers Schists are folded into the heart of the Easdale Schists; but they only extend a couple of miles west of the termination of their associated Ben-Lui Schists.

Enough has been said to show that the original interpretation of the district cannot support our present-day knowledge without extensive reconstruction. I shall now pass to the consideration of the new interpretation, which is the only one that I have been able to devise to take the place of the old.[1]

[1] [When in the summer of 1921 I revisited the ground with a small party of geological friends, I found myself criticized for not having explained in the text of my paper (here printed) how impressive a phenomenon the Ben-Lui Fold really is: I could only answer that, as I had in this instance added nothing material to the data collected by my predecessors, I thought brevity justified. At the same time, it is perhaps well to state that the Ben-Lui Fold is spectacular, according to South-West Highland standards—albeit

It will be readily understood that a small district does not afford opportunities for establishing a big structure. Accordingly, in reading this description, constant reference must be made from fig. 8 to Pl. I.

In the first place, although the superposition of Ben-Lawers Schists on Ben-Lui Schists in the upper limb of the Ben-Lui Fold is quite obvious in the immediate neighbourhood of Ben Lui, there is no local evidence to show that this order of superposition is of wide extent. To realize the importance of the upper limb of the Ben-Lui Fold, one has to remember the clear evidence from Loch Tay to Campbelton of the superposition of the Ben-Lui Schists on Loch-Tay Limestone—a superposition which continues for about 15 miles across the strike (p. 103). In this matter I have merely confirmed the findings of my predecessors.

Again, the superposition of Ben-Lui Schists on Ben-Lawers Schists in the lower limb of the Ben-Lui Fold is quite an obvious feature of the geology of the northern face of Ben Lui. The reality of the downward succession is enforced on anyone who descends the tectonic ladder connecting Ben Lui with Ben Udlaidh, where the Sub-Eilde Complex is so definitely exposed. The extent of country through which the lower limb of the Ben-Lui Fold has been traced will escape no one who recollects how Easdale Slates overlying Islay Quartzite have been followed from Ben Lui westwards round the outcrop of the Ardrishaig Phyllites into the Islay Archipelago.

Prof. Collet several times complained that grassy slopes compelled him to use his legs as well as his eyes to realize this fact. It may be helpful to record some important features recognized during our joint traverse:—

(1) Ardrishaig Phyllites form a prominent escarpment, Ra Chreag, where they overlie the Easdale Slates of the upper limb of the Ben-Lui Fold west of Allt Coire Lair (for place-names, see 1-inch map, Sheet 45).

(2) The junction of the Ardrishaig Phyllites and Easdale Slates can be located to within a foot or so at the base of Ra Chreag, in a stream which, at the valley-bottom, passes Corryghoil.

(3) The Easdale Slates below Ra Chreag are marked scenically by a grassy slope, where exposures are almost restricted to stream-courses.

(4) The Ben-Lawers Schists immediately below the Easdale Slates crop out as a subdued escarpment.

(5) Although the easternmost stream-exposure of the Easdale Slates is afforded by Allt Coire Lair, the Ardrishaig and Ben-Lawers escarpments are distinguishable for some distance farther. In Meall nan Gabhar the Ardrishaig escarpment seems to overreach its companion and come into direct contact with Ben-Lui Schists.

(6) The appearance of Meall nan Gabhar is very suggestive of a thrust-mass, riding upon a thrust-plane at the base of the Ardrishaig Phyllites. The features of Meall nan Gabhar almost certainly indicate that the bedding within the Ardrishaig Phyllites is much more steeply inclined south-south-westwards than is the base of the Ardrishaig escarpment. Probably the high dip is due to some species of schuppenstruktur, and its direction, as Mr. Richey pointed out to me, lends support to the view that the Loch-Awe Nappe has travelled in a general south-eastward direction. From this interpretation, it would follow that some of the many minor complications of the Loch-Awe Nappe belong, as might be expected, to the primary category of movements.—*E. B. B., January 1922.*]

The age-relations of the black slates and quartzites found above and below the Ardrishaig Phyllites no longer present a difficulty. From Dalmally westwards the large-scale movement has been accommodated by thrusting without inversion. The movement has been interpreted as having come from the north-west, because the Ben-Lui Fold, to judge from these same age-relationships, is a syncline closing in that direction.

IV. Conclusion.

Perhaps I may be pardoned for returning once again to two elements of Highland tectonics which should never be lost sight of. The first is the comparison of two sides of large-scale non-recumbent folds wherever these are recognizable; the second is the critical enquiry into any case where what seems to be a single rock-group has three—or more—distinctive margins. The first will always be connected in my mind with Clough and the Cowal Anticline; the second with Mr. H. B. Maufe, who, in the days before the recognition of slides in the Southern Highlands, was wont to insist that one of our main problems was the three-sided limestone of Ballachulish.

The beacon which has lighted the way in the development of the views expressed in the present paper has been the asymmetry of the Loch-Awe Syncline—on the one side the rocks of the Islay Archipelago, on the other those of Cowal. Is it credible that this asymmetry is due to change of facies? No,—the Islay rocks can be traced right under the Loch-Awe Syncline and away through Perthshire, not transformed into Cowal rocks, but in contact side by side.[1] As for the Cowal rocks, they too can also be followed for some distance beneath the Loch-Awe Syncline, but presently they are found to double back upon themselves, and thus to return whence they came.[2]

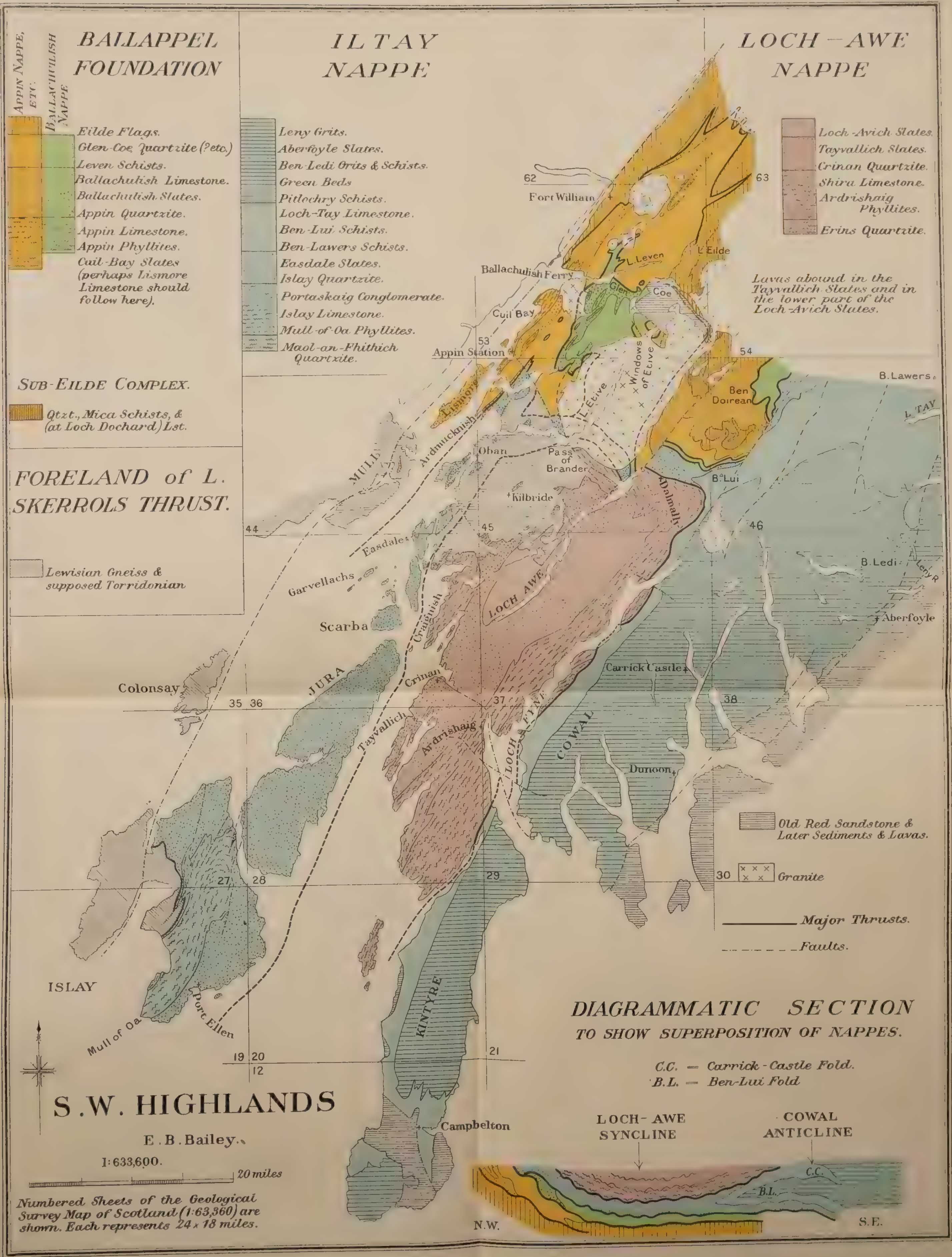
While it was easy to see this much, at any rate in a vague and general manner, still there was a difficulty in obtaining anything approaching to clear vision. The long-accepted correlation of the Ardrishaig and Ben-Lawers Schists blocked the way. But this correlation involved a three-sided formation (p. 121). It had, therefore, to be considered very critically. It was found unstable, and with its fall light gained access.

Appendix I—Bibliography.

1819. J. Macculloch.—'A Description of the Western Islands of Scotland & the Isle of Man, &c.'
1840. J. Macculloch.—Geological Map of Scotland, with Memoir (posthumous).
1852. D. Sharp.—'The Arrangement of the Foliation & Cleavage of the Rocks of the North of Scotland' Phil. Trans. Roy. Soc. vol. cxlii, p. 445.
1858. J. Nicol.—Geological Map of Scotland and Explanatory Note.
1859. R. I. Murchison.—'First Sketch of a New Geological Map of the North of Scotland' Q. J. G. S. vol. xv, p. 419.

[1] See also 1922, Report A, par. 8.
[2] *Ibid.* Report A, par. 6.

1861 (*a*). T. F. Jamieson.—'On the Structure of the South-West Highlands of Scotland' Q. J. G. S. vol. xvii, p. 133.
(*b*). R. I. Murchison & A. Geikie.—'The Altered Rocks of the Western Islands of Scotland & the North-Western & Central Highlands' Q. J. G. S. vol. xvii, p. 171.
1863. J. Nicol.—'The Geological Structure of the Southern Grampians' Q. J. G. S. vol. xix, p. 180.
1884 (*a*). C. Callaway.—'Notes on Progressive Metamorphism' Geol. Mag. p. 218.
(*b*). B. N. Peach & J. Horne.—'Report on the Geology of the North-West of Sutherland' Nature, vol. xxxi, p. 31.
1891. A. Geikie.—Presidential Address, Q. J. G. S. vol. xlvii, Proc. p. 63.
1892 (*a*). A. Geikie.—Geological Map of Scotland, revised 1910.
(*b*). 'Annual Report for 1891' Mem. Geol. Survey.
1897. W. Gunn, C. T. Clough, & others.—'The Geology of Cowal' (Explanation of Parts of Sheets 29 & 37), Mem. Geol. Surv. Scot. (Petrological Notes by J. J. H. Teall & F. H. Hatch).
1899. J. B. Hill.—'The Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe' Q. J. G. S. vol. lv, p. 470.
1903 (*a*). P. Macnair.—'The Building of the Grampians' Trans. Roy. Phil. Soc. Glasgow, vol. xxxiv, p. 147.
(*b*). W. Gunn.—'The Geology of North Arran' (Explanation of Sheet 21), Mem. Geol. Surv. Scot.
1904 (*a*). E. H. Cunningham-Craig.—'Metamorphism in the Loch Lomond District' Q. J. G. S. vol. lx, p. 10.
(*b*). 'Summary of Progress for 1903' Mem. Geol. Surv.
1905. C. T. Clough, J. B. Hill, & others.—'The Geology of Mid-Argyll' (Explanation of Sheet 37), Mem. Geol. Surv. Scot.
1906. P. Macnair.—'The Development of the Great Axial Lines of Folding in the Highland Schists' Trans. Roy. Phil. Soc. Glasgow, vol. xxxvii, p. 129.
1907 (*a*). S. B. Wilkinson (with B. N. Peach).—'The Geology of Islay' (Explanation of Sheets 19 & 27, and part of 20), Mem. Geol. Surv. Scot.
(*b*). B. N. Peach, J. Horne, & others.—'The Geological Structure of the North-West Highlands of Scotland' Mem. Geol. Surv. Scot.
[(*c*). C. Sarasin & L. W. Collet.—'La Zone des Cols & la Géologie du Chamossaire' Arch. Sci. Phys. & Nat. vol. xxiv, p. 586.]
1908 (*a*). P. Macnair.—'The Geology & Scenery of the Grampians.'
(*b*). H. Kynaston, J. B. Hill, & others.—'The Geology of the Country near Oban & Dalmally' (Explanation of Sheet 45), Mem. Geol. Surv. Scot.
1909 (*a*). B. N. Peach, H. Kynaston, H. B. Maufe, & others.—'The Geology of the Seaboard of Mid-Argyll' (Explanation of Sheet 36), Mem. Geol. Surv. Scot.
(*b*). 'Summary of Progress for 1908' Mem. Geol. Surv. Scot.
bibl: further. [illegible]
1910 (*a*). E. B. Bailey.—'Recumbent Folds in the Schists of the Scottish Highlands' Q. J. G. S. vol. lxvi, p. 586.
(*b*). E. B. Bailey.—'New Structures in the Argyllshire Highlands' Trans. Edin. Geol. Soc. vol. ix, p. 363.
(*c*). J. W. Gregory.—'Work for Glasgow Geologists—The Problems of the South-Western Highlands' Trans. Geol. Soc. Glasgow, vol. xiv, p. 1.
1911. B. N. Peach, C. T. Clough, E. B. Bailey, & others.—'The Geology of Knapdale, Jura, & North Kintyre' (Explanation of Sheet 28), Mem. Geol. Surv. Scot.
1912 (*a*). G. Barrow.—'On the Geology of Lower Dee-Side & the Southern Highland Border' Proc. Geol. Assoc. vol. xxiii, p. 274.
(*b*). E. B. Bailey & M. Macgregor.—'The Glen-Orchy Anticline (Argyllshire)' Q. J. G. S. vol. lxviii, p. 164.
1913 (*a*). 'Summary of Progress for 1912' Mem. Geol. Surv.
(*b*). E. B. Bailey.—'The Loch-Awe Syncline (Argyllshire)' Q. J. G. S. vol. lxix, p. 280.
1914. E. B. Bailey.—'The Ballachulish Fold near the Head of Loch Creran (Argyllshire)' Q. J. G. S. vol. lxx, p. 321.
1916. E. B. Bailey, H. B. Maufe, & others.—'The Geology of Ben Nevis & Glen Coe, &c.' (Explanation of Sheet 53), Mem. Geol. Surv. Scot.
1917 (for 1916). E. B. Bailey.—'The Islay Anticline (Inner Hebrides)' Q. J. G. S. vol. lxxii, p. 132.


BALLAPPEL FOUNDATION
APPIN NAPPE, ETC.
BALLACHULISH NAPPE
Eilde Flags.
Glen-Coe Quartzite (?etc.)
Leven Schists.
Ballachulish Limestone.
Ballachulish Slates.
Appin Quartzite.
Appin Limestone.
Appin Phyllites.
Cuil-Bay Slates (perhaps Lismore Limestone should follow here).
SUB-EILDE COMPLEX.
Qtzt., Mica Schists, & (at Loch Dochard) Lst.
FORELAND of L. SKERROLS THRUST.
Lewisian Gneiss & supposed Torridonian
ILTAY NAPPE
Leny Grits.
Aberfoyle Slates.
Ben-Ledi Grits & Schists.
Green Beds
Pitlochry Schists.
Loch-Tay Limestone.
Ben-Lui Schists.
Ben-Lawers Schists.
Easdale Slates.
Islay Quartzite.
Portaskaig Conglomerate.
Islay Limestone.
Mull-of-Oa Phyllites.
Maol-an-Fhithich Quartzite.
LOCH-AWE NAPPE
Loch-Avich Slates.
Tayvallich Slates.
Crinan Quartzite.
Shira Limestone.
Ardrishaig Phyllites.
Erins Quartzite.
Lavas abound in the Tayvallich Slates and in the lower part of the Loch-Avich Slates.
Fort William
Ballachulish Ferry
Cuil Bay
Appin Station
Lismore
Ardmucknish
L. Leven
Glen
Coe
L. Eilde
L. Etive
Windows of Etive
Ben Doirean
B. Lawers
L. TAY
Oban
Pass of Brander
Kilbride
Dalmally
B. Lui
MULL
Easdale
Garvellachs
Scarba
Craignish
LOCH AWE
B. Ledi
Leny R.
Aberfoyle
Colonsay
JURA
Crinan
Tayvallich
Ardrishaig
LOCH FYNE
Carrick Castle
COWAL
Dunoon
ISLAY
Mull of Oa
Port Ellen
KINTYRE
Campbelton
62
63
53
54
44
45
46
35
36
37
38
27
28
29
30
19
20
21
12
Old Red Sandstone & Later Sediments & Lavas.
Granite
Major Thrusts.
Faults.
DIAGRAMMATIC SECTION TO SHOW SUPERPOSITION OF NAPPES.
C.C. = Carrick-Castle Fold.
B.L. = Ben-Lui Fold
LOCH-AWE SYNCLINE
COWAL ANTICLINE
C.C.
B.L.
N.W.
S.E.
S.W. HIGHLANDS
E. B. Bailey.
1:633,600.
20 miles
Numbered Sheets of the Geological Survey Map of Scotland (1:63,360) are shown. Each represents 24 x 18 miles.

1930- Geol Mag.

1922. 'The Structure of the South-West Highlands of Scotland. Two Reports on an Excursion, August 27th to September 2nd, 1921.' Report A by E. M. Anderson, H. H. Read, J. E. Richey, & W. B. Wright. Report B by L. W. Collet. Geol. Mag. (in the press).

In addition to the above, the Geological Survey has published Sheets 12, 19, 20, 21, 27, 28, 29, 30, 35, 36, 37, 38, 45, 46, and 53 of the 1-inch (1 : 63,360) Map of Scotland; also a special Map of Arran on the same scale; Sheet 13 (Islay) ¼ inch to 1 mile; and a general map of Great Britain & Ireland on the scale of ·25 miles to the inch.

Appendix II—Locality-Index.

Scottish localities mentioned in the text, and at the same time not indicated in Pl. I, are enumerated alphabetically below. Their positions are stated by coordinates within the various numbered sheets of the Geological Survey 1 : 63,360 map of Scotland; many of these sheets are outlined on Pl. I :—

For example, Airds Bay lies 2 miles west and 17 miles north of the south-western corner of Sheet 45 : Airds Bay, 45, 2, 17 ; Airds Hill, 45, 4, 17 ; Aonach Beag, 53, 20, 16 ; Appin, district including Appin Station, 53, 4, 0, and Port Appin, 45, 2, 17 ; Ardentinny, 45, 1, 15 ; Ardmucknish Bay, 45, 2, 12 ; Argyllshire, stretching eastwards to Ben Lui, 46, 1, 6.

Ballachulish, district with Ballachulish Village (East and West Laroch), 53, 13, 7, and Ballachulish Ferry, 53, 12, 8 ; Baracaldine Castle, 45, 3, 14 ; Beannan Dubh, 27, 21, 2 ; Beinn Bheula, 37, 20, 6 ; Beinn Udlaidh, 46, 2, 10 ; Ben Vrackie, 55, 19, 12 ; Ben y Glo (Beinn a'Ghlo), 64, 20, 0 ; Blair Athol, 55, 14, 13 ; Blarcreen Burn, crossed by road at 45, 8, 11 ; Bonawe Ferry, 45, 9, 9.

Camas an Fhais (Camas Nathais), 45, 1, 12 ; Coire Mhorair, 53, 19, 7 ; the Crinan Canal follows a fault south-eastwards from Crinan to Loch Fyne.

Eilean Duirinnis, 45, 9, 10 ; Erins, 29, 1, 9 ; Eriska, 45, 2, 15.

Garbh Ard, south-eastern headland of Ardmucknish, 45, 1, 12 ; Glen Creran, south-eastern valley in 53, mouth at 45, 9, 17 ; Glen Etive, valley passing through the Windows of Etive, 53, 18, 2 ; Glen Orchy, south-eastern valley through 46, 0, 10 ; Glen Shira, south-eastern valley, mouth at 37, 16, 14 ; Glen Sluan, hamlet, 37, 15, 7 ; Glen Spean, east-and-west valley through, 62, 23, 4 ; Glen Strae reaches Loch Awe, 47, 17, 7.

Inveresragan, 45, 8, 11.

Killiekrankie Pass, 55, 17, 11 ; Kilmory Bay, 28, 15, 9 ; Kinlochleven, 53, 20, 10.

Lairigmore Pass, 53, 16, 11 ; Ledgrianoch Farm, 45, 4, 16 ; Leny Pass, 38, 21, 13 ; Loch Avich, 37, 5, 16 ; Loch Creran, 45, 6, 16 ; Loch Dochard, 45, 22, 15 ; Lochan Dubh, 45, 3, 14 ; Loch Eck, 37, 18, 0 ; Loch Goil, 37, 22, 6 ; Loch Lomond, 38, 10, 0 ; Loch na Cille, 28, 14, 12 ; Loch Skerrols, 27, 17, 1 ; Loch Torridon, 81, 15, 16 ; Luing Island, 36, 17, 13.

Maol an Fhithich, 19, 14, 8 ; Meall a'Bhuirich, 53, 24, 15 ; Meall nan Tighearn, 45, 23, 4 ; Moine, 114 central.

Perthshire, east of Ben Lui, 46, etc. ; Pitlochry, 55, 18, 9 ; Portaskaig, 27, 22, 5.

River Esragan, bend at 45, 8, 12 ; Ross-shire, 92, etc. ; Rudha Garbh, 45, 4, 14.

Schiehallion, 55, 4, 6 ; Selma, 45, 2, 12 ; Shira (see Glen Shira) ; Skye, 70 & 71 ; Southern Uplands, south of line from 14, 0, 0 to 33, 19, 15 ; Stack of Glen Coul, 107, 23, 6 ; Strath Appin, east-north-eastern valley through, 45, 5, 17 ; Strathappin Farm, 45, 5, 17 ; Stronchullin, 29, 0, 12 ; Sutherland, 101, etc.

Tappins, 8, 10, 15 ; Torridon (see Loch Torridon).

EXPLANATION OF PLATE I.

Generalized geological map of the South-West Highlands, based upon the 1-inch map of Scotland of H.M. Geological Survey ; revised and reduced by the Author. Scale : 10 miles = 1 inch, or 1 : 633,600. The numbered divisions correspond with the sheets of the 1-inch map.

Discussion.

Mr. G. Barrow regretted that he had been unable to follow the Author in his repeated references to different districts. Having visited much of the area, he did not agree either with the Author's view of the structure of the country or his nomenclature of the rocks. The existence of the 'nappes' shown on the map seemed most unlikely, as the speaker felt sure that individual beds could be traced across from one to the other. Judging from some of the lantern-slides exhibited, he suspected that the supposed 'nappes' were simply different aureoles of thermal alteration, similar to those mapped out in the South-Eastern Highlands, which were shown in detail in the pamphlet prepared by the speaker for the use of the Geologists' Association, at the Dundee Meeting of the British Association.

Dr. J. S. Flett said that everyone interested in Highland geology admired the enthusiasm with which the Author had attacked the problems under discussion. It was a task of extreme difficulty to unravel the structure of the Southern Highlands, and no means of accomplishing that end could be neglected. Among others, recent geological work in the Alps has furnished new ideas, especially in regard to the features of 'nappes,' which were sure to be applied to the Scottish Highlands, and were likely to prove of cardinal importance. In his paper the Author had suggested that in Argyllshire three 'nappes' could be recognized. He had discarded the sequence hitherto adopted by Scottish geologists, and advanced a new correlation which was in harmony with his views of the structure.

The speaker, while recognizing the attractive character of the Author's hypotheses, did not feel convinced that the solution now offered was established on an incontrovertible basis. The vast movements postulated did not seem to have produced a corresponding effect on the outcrops. The rocks of Ballachulish and Loch Awe were very much those which would be expected to occur there if no 'slides' existed, or if the 'slides' were of small magnitude. The Ballachulish slide, for example, did not seem, in a large part of its course, to have shifted the outcrops to a notable extent. This might be because, as the Author suggested, the movement was very nearly parallel to the bedding-planes. But great movements could not be so confined, and we might expect, occasionally at any rate, to find that beds were brought into juxtaposition which normally were widely separated. So far as the speaker had seen, the evidence both of the maps and of the natural exposures was not in favour of the large movements in which the Author believed. It was very desirable that a clear case of transport, with difference of facies in the exotic and the autochthonous beds and something resembling a visible thrust-plane should be brought to light. The Author's slides were practically confined to the outcrops of the Central Highland Series (from the

Appin Limestone to the Leven Schists) and, so far as the evidence went, might be purely local adjustments due to the folding of that group.

Of the Loch-Awe Nappe it was difficult to form a clear opinion. The presence of a volcanic group in that district did not necessarily imply that these rocks were not in place, as volcanic eruptions were often localized, and lavas had been found on what the speaker believed to be the same horizon, in Upper Banffshire. The 'Boulder-Bed' occurs in Islay, in Tayvallich, in Perthshire, in Aberdeenshire, and in Banffshire, always in association with a quartzite, limestone, and black or grey shales, and forms certainly one of the most useful landmarks in the correlation of Highland rocks. In that case the Loch-Awe Series could be traced from Islay to Portsoy and the Ballachulish Series from Ardmucknish (or perhaps Easdale) to the shores of the Moray Firth, and the variation was by no means great. It was difficult to understand how in Loch Awe and Ballachulish, despite enormous displacements, the rocks were exactly of the type which occurred in similar positions everywhere along the southern edge of the Moine Gneiss.

The Argyllshire nappes were evidently of an entirely different type from their Swiss analogues. The Scottish nappes rested on no marked plane of disturbance; they have no 'roots'; their facies is that of the country in which they are found; their metamorphism is similar to that of the surrounding rocks; they are not markedly transgressive; and they seem to differ in no important respects from autochthonous strata. At present, it was necessary to place them to a suspense account. Nothing would be more welcome to Scottish geologists than the proof that Alpine tectonics were repeated in typical development in the Southern Highlands, but much work had still to be done before that day arrived.

Mr. H. H. Read said that all workers in the Highlands were greatly indebted to the Author for his application of the wonderful results achieved by Alpine geologists to the solution of Highland problems, but the speaker considered that the major structures of the Highlands, owing to the metamorphosed condition of Scottish rocks, could never be demonstrated with even a small part of that definiteness which characterizes Alpine tectonics.

It was unfortunate that there was so little correspondence between the metamorphic zones and the structural features of the ground described by the Author, and this, together with the absence of dislocation-metamorphism (not necessarily mylonization), especially in the Loch-Awe region, was, in the speaker's opinion, a somewhat serious objection to the Author's interpretation. The Author's suggestion that the presence of carbon in the Ballachulish Slates had prevented the formation of garnet did not apply to the garnetiferous, graphitic, and carbonaceous schists of Banffshire.

The speaker would welcome some information as to where the

Author considered the roots of his nappes to lie. The 'Iltay' assemblage could be followed from Perthshire into Banffshire, where the speaker had worked for several years. Away to the north-west of the Banffshire rocks stretched Moine granulites for 70 miles to the thrust-ground of the North-West Highlands. If the roots were in the thrust region, were they covered by the thrusts? The Moine region, the speaker held, carried nothing suitable as roots for the Dalradian assemblage.

The Author suggested that the 'Ballappel Foundation' was characterized by Eilde Flags and Glencoe Quartzite. But in Banffshire the speaker found rocks of 'Iltay' facies linked inseparably on the west with a quartzite and granulites of Glencoe and Eilde types. If the Banffshire Dalradian rocks were to be included in the 'Iltay' nappe, then so must a large part of the Moine Series be similarly included. The phenomena of the Great-Glen Fault appeared to indicate to the speaker that the Dalradian rocks overlay the Moine Series. But the Author, in his table, showed the Eilde Flags at the top: the speaker disagreed with that sequence. Correlation from Banffshire to Perthshire could be made in some detail, and, if the Author's table for the 'Iltay' nappe were read from bottom to top, similar rock-types occurred in Banffshire from west to east. But correlation could be made, with equal chances of proving correct, from Banffshire into the 'Ballappel Foundation.' The Banffshire rocks, from west to east, were exactly like the Author's 'Ballappel' table read from top to bottom, and the speaker considered that this table should be reversed, so as to place the Eilde Flags at the bottom. That complicated still further the Ballachulish structures.

The speaker believed in the reality of sliding or thrusting, but he considered that the existence of nappes in the South-West Highlands had not yet been demonstrated.

Lord Clifford remarked that the Author's evidence concerning the irregular folding of some of the strata in this part of Scotland appeared to support a theory that the speaker had long held, that folds and faults are mainly due to oceanic subsidences. Between a line drawn from the Firth of Lorne to the Moray Firth on the north, and a line drawn from Morecambe Bay to Sunderland on the south, there lies a tract of country that has been subject to more strain and contortion than almost any other portion of the world. The folding of this part of Britain and the reversal of strata in the manner described by the Author are results that one would naturally expect.

The Author, in reply, said that Dr. Flett's statement that Scottish geologists were searching the Highlands everywhere for analogues of Swiss structures might, perhaps, convey a wrong impression. The speaker, as a matter of fact, developed his interpretation of the Ballachulish district before reading the Alpine literature or visiting the Alpine exposures. It had been an added pleasure to find, on comparison of the two mountain-

chains in the field, how close the resemblances were. It was an asset to the new reading of the Highlands to have opponents of the standing of Dr. Horne and Dr. Flett, for it invited critical enquiry. The only regret that the speaker felt was that these two opponents had not investigated the field evidence. One claim at least might be made for the interpretations that the speaker had put before the Society: they did conform with exposed outcrops. On the other hand, while Dr. Flett had been speaking, it was often difficult to realize that he intended his remarks to apply to the South-West Highlands.

The Author apologized for the lateness of the hour preventing him from answering in detail points raised by other speakers, and added that a small committee of geologists in Scotland had volunteered to investigate any criticism of the paper that might be tabled, so long as it dealt with mainland exposures.

3. *The* Bala Country: *its* Structure *and* Rock-Succession.

By Gertrude Lilian Elles, M.B.E., D.Sc., F.G.S. (Read March 9th, 1921.)

[Plate II—Geological Map.]

Contents.

I. Introduction.

The district dealt with in the present paper lies all round Bala Lake, though attention has been paid more particularly to the ground lying south-east and east of the lake, as affording an opportunity for the study of problems of special interest regarding the succession and structure of the area.

The whole district has been classic ground since the days of Sedgwick, and its difficulties were vividly described later by Jukes; it is just these difficulties that make the area so intensely interesting, and, largely owing to the more detailed mapping that can be carried out in these days, it is now possible to suggest a solution of some, at any rate, of the problems—more particularly those of a stratigraphical and structural nature. The palæontological problems are somewhat different, and will not be dealt with in detail at present.

Previous Work.

By far the most important contributions made to our general knowledge of the district are those of Sedgwick, Jukes, and Ruddy, though Ramsay and, in later times, Lake have dealt with the question of the faulting as connected with the development of the valley in which the lake lies.

Sedgwick made two important contributions to the study of the area. In the earlier paper on the 'Calcareous Slates & Limestones of Glyn Dyffws on the Holyhead Road, west of Corwen, & of Rhiwlas north-east of Bala,'[1] he gave what he believed to be the succession in the area, and illustrated it by sections made as

[1] Proc. Geol. Soc. vol. iv (1843) p. 252.

early as 1832. This paper was later incorporated into a more general treatise.[1] As he did not fully realize the complexities of the structure of the country, Sedgwick's succession has naturally undergone some modification in later days, but the papers are noteworthy since he clearly understood that the faunas of the Rhiwlas and Bala Limestones were distinct; he drew attention, moreover, to the nature of the beds above the Bala Limestone, and indicated the true position and character of the Hirnant Limestone.

J. de C. Sowerby & J. W. Salter, who contributed notes on the fossils, remarked on the paucity of brachiopods in the Rhiwlas Limestone as compared with their abundance in the Bala Limestone, mention being made of *Orthis actoniæ* as a highly characteristic form. They also record the distinctive peculiarities of the brachiopods of the Hirnant Limestone.

In the paper published in 1852[2] on the 'Classification & Nomenclature of the Lower Palæozoic Rocks of England & Wales,' Sedgwick notes the Coniston Limestone as the equivalent of the Bala Limestone, and subdivides the Bala Group of rocks into an Upper and Lower, the Upper Bala beginning with the Bala Limestone, including the Hirnant Limestone and Shelly Sandstone, and ending with the dark indurated Shales, passing in places into a bad pyritous roofing-slate. The position of the Rhiwlas Limestone is not indicated in this paper.

The area was officially surveyed by J. B. Jukes, and the results of his work are given in the two editions of the Geological Survey Memoir on North Wales.[3] It is marvellous that Jukes was able to show so much on the 1-inch map, and it is clear from his notes that his general conclusions accorded more completely with those that I have reached than the 1-inch map would indicate, although my own conclusions have only been arrived at after laborious mapping on the 6-inch, and often on a still larger scale. Thus, in the end, Jukes was convinced that there was only one ash-bed in the lower part of the series east of Bala Lake, although he notes the possibility of the existence of more elsewhere, and records the occurrence in places of a definite ash-bed immediately below the limestone. My work has confirmed the existence of only one ash in the lower part of the series, not merely in the area east of the lake, but on the west side also, and again in the ground on the north so far as I have seen it. Jukes is also perfectly definite as to the nature of the Bala Limestone, and, from his remarks concerning the ash immediately below the limestone, it seems evident that he included in the Bala Limestone not only the massive limestones, but the whole of the Calcareous Ash—in fact, he

[1] Q. J. G. S. vol. i (1845) p. 6.
[2] *Ibid.* vol. viii, p. 136.
[3] Mem. Geol. Surv. vol. iii (1866) chaps. xiii & xiv; vol. iii, 2nd. ed. (1881) chaps. xv & xvi.

states that the limestone is ashy in places, and also non-calcareous occasionally, 'when it is not to be differentiated from the sandstones.' He does not, however, consider that the Bala Limestone is distinct from the Rhiwlas, being unappreciative of the value of the palæontological evidence.

He records the existence and nature of the Hirnant Limestone at the head of the Hirnant Valley, and notes the position of beds of the same age at other localities.

His remarks on the structure of the country are highly suggestive: he notes the existence of the anticlinal line separating the synclinal lines of Bryn Pig and Creigiau Bychain,[1] notes the broken nature of the ash outcrops, and calls attention to the parallelism of certain lines of faulting. He also suggests that the lake lies in a trough open to the south, of which the apex lies north of Moel Emoel at Pen y Bwlch-gwyn. He estimates the thickness of the beds between the ash and the limestone as ranging from 1200 to 1400 feet.

In his admirable paper 'On the Upper Part of the Cambrian & Base of the Silurian in North Wales,' Thomas Ruddy[2] describes definite lines of section, and makes the earliest attempt at a palæontological classification of the beds, the fossils from each horizon being sedulously recorded and the actual succession seen at certain localities carefully described. The nature of the Hirnant Beds, apart from the limestone, is noted, and attention is drawn to the change in character which they undergo when traced along their strike as also their relation to the overlying Tarannon Beds.

Ruddy was an indefatigable collector, although his collections were not always made from beds *in situ*, and his fossil lists have been of the greatest service to me, especially the summary given in his 'List of Caradoc or Bala Fossils found in the Neighbourhood of Bala, Corwen, & Glyn Ceiriog.'[3]

Ruddy's sections are generally easy to follow, with the exception of that across Gelli Grin, where the faulting of the beds appears to have escaped his notice, and therefore two ash-beds are noted instead of one. He accepts the official view as to the identity of the Bala and Rhiwlas Limestones, but considers the Hirnant Beds to be of Llandovery age.

Sir Andrew Ramsay[4] was the first to mention the continuity of the Dee-Valley and Bala-Lake fault, stating that it has an invariable downthrow to the north-west, so that part of the strata south and east of the lake are repeated by it and reappear on the west and north.

He estimates the maximum amount of throw as 12,000 feet;

[1] The spelling of the place-names adopted in this paper is that used in the 6-inch Ordnance Survey maps.
[2] Q. J. G. S. vol. xxxv (1879) p. 200.
[3] Proc. Chester Soc. Nat. Hist. no. 3 (1885) p. 113.
[4] Q. J. G. S. vol. ix (1853) p. 161.

but, later in the Geological Survey Memoir on North Wales (2nd ed. 1881), he gives 11,000 feet as a more probable figure, and states that the throw diminishes north-westwards in the region of the lake to 5000 feet. The angle of the fault, as drawn, shows a steep north-north-westward dip, but it is admitted that the angle is hypothetical.

Philip Lake, in his paper on 'Bala Lake & the River-System of North Wales,'[1] deals with the faults in the region south-west of the lake, and considers that there are two faults traversing the lake, one parallel to the south-eastern shore (though some little distance within the water's edge) and the other parallel to the north-western shore.

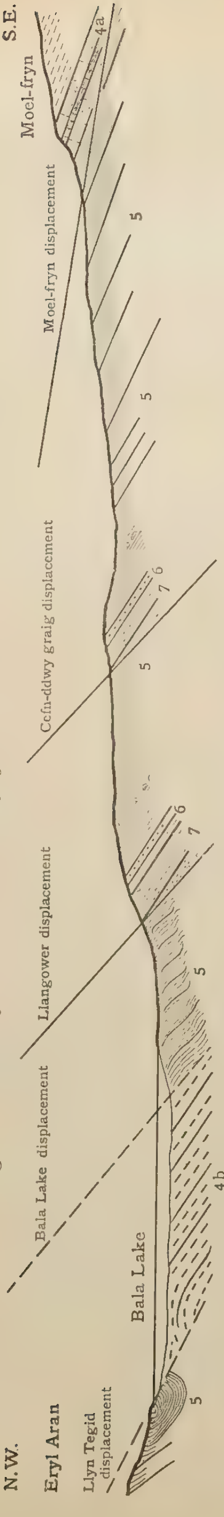
In his paper on the 'Composition & Structure of the Hirnant Limestone,' L. W. Fulcher[2] points out that the grains in the rock are ellipsoidal in shape, measuring 1 to 3 mm. in their longest diameter, and they are more sparsely scattered in the crystalline matrix than in an ordinary oolite or pisolite; he also notices that the blackness of the grains, which is so marked a feature of the rock, is due to the presence of carbon in an amorphous form.

II. General Physical Features.

The country is essentially a hilly one: on the south-east of the lake the ground rises steeply from lake-level (530 feet) to 1000 feet, the steepest part of this rise appearing to coincide with a well-marked line of fault; above the altitude of 1000 feet, however, the slopes are gentler and less regular up to the summit of Moel-fryn (1750 feet); beyond the summit the ground falls somewhat rapidly into the steep-sided Hirnant Valley, but rises again beyond to a height of about 2000 feet. On the north-west side of the lake the rise is also steep to the 900-foot contour-line, and is probably determined by another fault-line. Above this height there is a marked contrast with the opposite side of the lake, for there is a wide stretch of merely undulating moorland with scarcely any rise until the base of Arenig is reached, when the ground rises very steeply to the twin-peaked summit of Arenig Fawr (2800 feet), this being the most conspicuous height in the district. There is a far more gradual rise towards the hilly country lying on the north. The valleys are, as a rule, conspicuously deep and steep-sided, and are occupied by swiftly running streams, though, with the exception of Nant Rhyd Wen, they are still largely filled with Drift. Only one stream appears to show any features of interest, and that is the Hirnant: starting as a strike stream, it soon makes a bend at right angles to its former course through Bwlch-yr-Hŵch, although the existence of a well-defined channel

[1] Geol. Mag. 1900, pp. 204, 241.
[2] *Ibid.* 1892, pp. 114, &c.

Fig. 1.—*Section from Bala to Moel-fryn.* (*Horizontal scale: 3 inches = 1 mile.*)



4 *a* = Gelli-Grin Calcareous Ash with Moel-fryn Limestone.
4 *b* = Moel-fryn Sandstones.
5 = Allt-Dhu Mudstones.
6 = Fronddерw Ash.
7 = Glyn-Gower Sandstones.

The Rhiwlas Mudstones cap the section on the extreme right.

in the original direction at some height above its present course is suggestive of capture by a stream with greater corrosive power, possibly due to the Bwlch-yr-Hŵch Fault. The Hirnant continues to run as a strike stream again as far as Aber Hirnant, where it makes another bend; and the lower part of its course is clearly controlled by the structure of the country.

III. The General Succession.

The rock-succession here described comprises pre-eminently a series of shallow-water deposits; even the black Nant-hir Shales appear to be current-bedded, and to this we may perhaps ascribe their unfossiliferous nature. The Sandy Mudstones contain bands and even whole beds ripple-marked and to some extent also current-bedded, while the oolitic nature of the Gelli-Grin Limestone at Y Garnedd points in the same direction.

The succession is interesting, mainly on account of the development of the ashes and limestones. The ash-beds, of which there are two in all, belong to the Caradocian; both die out southwards, although the lower is the more persistent, and both serve admirably to bring out the structure of the country. The limestones are remarkably impersistent, and occur more or less sporadically throughout the series; they have little or no value as stratigraphical units.[1]

[1] Some places mentioned in the following pages lie outside the area of the accompanying map (Pl. II), but they may be found on the 1-inch Ordnance Map and on the 1-inch Geological Map, Sheets 74 N.W. & S.W.

		Shelly Faunas.	Graptolite Zones.
VALENTIAN.	Cwm-yr-Aethnen Shales.		Zone of *Monograptus crispus.* Zone of *M. sedgwicki.*
	Hirnant Grits and Mudstones, including local Hirnant Limestone.	*Orthis-hirnantensis* fauna.	
ASHGILLIAN.	Foel-y-Ddinas Mudstones.	*Phacops-mucronatus* fauna.	
	Moel-fryn Sandstones.	Unfossiliferous.	
	Rhiwlas Limestone and Mudstones.	*Phillipsinella parabola* fauna.	*Dicellograptus-anceps* Zone.
CARADOCIAN.	Gelli-Grin Calcareous Ash, with Gelli-Grin (Bala) Limestone, Moel-fryn Limestone, Bryn-Pig Limestone, Caerhafotty Limestone.	*Calymene-planimarginata* fauna. *Chasmops* & *Nicolella-actoniæ* fauna.	
	Pont-y-Ceunant Ash.		
	Allt-Ddu Mudstones.	*Asaphus-powisi* & *Heterorthis-alternata* fauna.	*Dicranograptus-clingani* Zone.
	Frondderw Ash.		
	Glyn-Gower Sandstones.		
LLANDILIAN.	Nant-hir Shales and Derfel Limestone.		*Climacograptus-peltifer* Zone.

Dicranograptus Shales and Derfel Limestone.

Resting upon the well-known Volcanic Series of the Arenig Mountains come the *Dicranograptus* Shales, in this area conspicuously devoid of fossils except at the base and summit, and of somewhat different lithological character from those developed in other Welsh areas. In the Bala district they consist, for the greater part, of hard, black, gritty shales with sandy wisps, showing in many sections a structure strongly suggestive of current-bedding. Close to their base they contain the Derfel Limestone recorded by Prof. W. G. Fearnsides as the *Orthis* or Derfel Limestone[1]; the shales with which this limestone is interbedded are

[1] Q. J. G. S. vol. lxi (1905) p. 627.

rather softer than those at a higher horizon, and have yielded a few graptolites (see p. 144); but elsewhere no traces of any organism have been found, although the shales are magnificently displayed along the course of the Nant-hir flowing down from the slopes of Arenig across their strike. The shales appear to roll somewhat, and one marked fold brings up the volcanic rocks again; they may also be repeated to some extent by strike-faulting, although in the absence of fossils the magnitude of such repetition cannot be estimated: they are probably affected to some extent by tear-faults, but again the degree of this is difficult to detect in the absence of any clue as to the relative age of the beds, and owing to the fact that they are widely concealed beneath a tract of heathery moorland. Towards their upper limit the shales again become somewhat softer, but at this horizon beds of hard sandy mudstone begin to be intercalated among them; these gradually increase in number and importance, until they pass over into a definite series of fine massively-bedded sandstones containing an appreciable quantity of mica.

Glyn-Gower Beds.

This series is well exposed in many places, especially in Glyn Gower, probably by reason of its nature, and is distinguished by its hardness and widely-separated bedding-planes; the coarser beds gradually give place upwards to bands of finer texture, of the nature of sandy mudstones. These not only contain some shale-bands, but also a certain amount of calcareous material in the form of concretions of all sizes; the commonest of these concretions are about the size of a man's head: in places, however, where they have been worked for lime (as on Bryniau Goleu) they are considerably larger. The shale-bands as a rule are somewhat cleaved, although the cleavage rarely is sufficiently well-developed to obliterate the bedding. It is in these sandy mudstones that the lowest ash-bed occurs. Although the beds immediately above and below the ash are very much alike, yet, taking them as a whole, a marked difference may be noted in the lower beds both in general lithological characters and in their fossiliferous nature, so that they may be conveniently separated off as constituting a series by themselves, the Glyn-Gower Beds. These deposits are but sparsely fossiliferous, and, although the fauna is everywhere meagre and lacks the variety of the higher beds, yet it is not wholly devoid of interest. In the black shales occurring in the sandy mudstones graptolites have been found (*Orthograptus truncatus*), and the bedding-planes of the massively-bedded sandy mudstones are occasionally covered with *Plectambonites sericea*—in fact, this fossil, together with *Glyptocrinus basalis*, is so much the commonest organism found that (from the palæontological point of view) the series might well be termed the *Plectambonites-sericea* Beds.

Frondderw Ash.[1]

There is no hard-and-fast line to be drawn between the sandy mudstones and the ash, for wisps of ash at first show themselves in the sandy mudstones, then a thin band or two of definitely ashy material is commonly found, and finally a bed of massive ash is seen, having a maximum thickness of 12 feet; towards the top it behaves much in the same way, mudstone wisps making their appearance, and the whole passing into an ashy mudstone in which the ashy material gradually diminishes until it has completely disappeared. The massive portion of this rock makes a conspicuous feature in the landscape wherever it occurs, and at close quarters is easily recognizable by its rough weathered surface, upon which the fragments are sometimes very conspicuous. It seems to be typically developed in the more northerly parts of the area, becoming thinner and less distinctive towards the south, where it is associated with a local development of limestone, and is split into two thin bands with mudstone between them. When last seen (Cefn Gwyn) it is merely an ashy mudstone quickly becoming indistinguishable from the surrounding sandy mudstones, which at this locality have yielded some interesting Ophiurids (*Protaster salteri*).

This ash has been most extensively quarried throughout the district for walls and farm-buildings, so much so, that nearly all the exposures on the north-west side of the lake have been worked all along their strike, and the rock is only now visible at the very base of a small cliff of sandy mudstone, and in many cases is largely concealed by rubble. One of the most conspicuous of these outcrops lies north of Frondderw. Under the microscope this ash is seen to be of a very felspathic nature, being made up mainly of fragments of a coarsely vesicular felspathic lava, some of which are devitrified, fragments of a coarsely crystalline rock suggestive of an intrusion, and a few pieces of an oolitic limestone. It is definitely less siliceous than the Pont-y-Ceunant Ash.

Allt-Ddu Mudstones.

The sandy mudstone series above the Frondderw Ash quickly takes on a different character from those below; while the beds immediately above the ash are very similar in their general character to the sandy mudstones below, and contain certain bands with concretions of a practically identical nature, softer beds come in with increasing rapidity. The beds quickly lose their pronounced sandiness, beds of this nature being confined to narrow partings only a few inches thick; the colour becomes dark bluish-grey instead of pale blue-grey, and the rocks are often iron-stained in irregular blebs: the whole series is intensely cleaved, so much

[1] I am indebted to Dr. R. H. Rastall for kindly confirming my examination of the slices of this and the Pont-y-Ceunant Ash.

so that the bedding is often quite obliterated on the weathered surface, in marked contrast to the prevalent clear stratification of the beds below the ash. The cleavage throughout the district is commonly north 10° east, and dips a little east of south. In the higher parts of this series some very fine-grained harder bands make their appearance: these, when weathered, exhibit a peculiar smoothed surface, and when glaciated may take on a very high polish; their bedding-planes are commonly about 6 inches apart, and they are very easily recognized in the field. They are not of themselves very fossiliferous; but, since they resist cleavage to an extent comparable with that of the hard sandy mudstones of the Glyn-Gower Series, the fossiliferous surfaces of the softer beds in which they are intercalated are often well preserved in a series of dip-slopes and scarps, forming a conspicuous and distinctive feature in the landscape.

An especially good series of the scarps and slopes is seen all along Allt-Ddu, from which these beds derive their name, though they are also well displayed at Bryn-bedwog, Bryn Porfa, Bryn-yr-aber, and on Cefn-ddwy-graig.

In these Allt-Ddu Beds the fauna is both rich and varied, the bedding-surfaces being often crowded with numerous brachiopods, of which *Heterorthis alternata* and the variety *retrorsistria*,[1] *Platystrophia biforata*, and *Dinorthis flabellulum* are the most conspicuous; while among the trilobites a big *Asaphus* of the *powisi* type, *Trinucleus gibbifrons*, and *Calymene caractaci* are characteristic, though less abundant. *Heterorthis alternata* and its variety *retrorsistria* are by far the most numerous fossils found, so that the beds may appropriately be termed the *Heterorthis alternata* Beds, a name long ago given to them by Ruddy.

Pont-y-Ceunant Ash.

The Pont-y-Ceunant Ash succeeds the Allt-Ddu Beds, but its junction with these mudstones is characteristically very irregular, as may be well seen in the quarry at Y Garnedd, where the ash has been extensively quarried: it has a thickness of about 25 feet in the northern part of the district, the only part of the area where it is at all really well-developed; southwards it becomes more completely merged in the Calcareous Ash, until in the neighbourhood of Bryn-Pig only the lowest part (1 to 2 feet) can be

[1] Thomas Davidson first regarded this fossil as a variety of *H. alternata*, but subsequently, upon the evidence of specimens from Cerrig-y-druidion now in the Sedgwick Museum, he raised it to the rank of a distinct species (Appendix to 'Silurian Brachiopoda'). These specimens, however, in common with all from the same locality, have suffered severely from the deformation of the rocks in which they lie, and cannot be regarded as normal. Specimens of the same fossil from many other Welsh localities appear to be so very close in general structural details to *H. alternata*, apart from the more conspicuous bending-back of the surface-ribbing, that I regard Davidson's original diagnosis as the more satisfactory.

separated as a definite ash, retaining its coarse character, while at Creigiau Bychain it does not exceed 6 inches in thickness, as distinct from the Calcareous Ash. It is very variable in character also, varying even in one quarry from a very coarse to an even-grained rock of fine texture containing mudstone patches; at times, also, there is very little ashy material beyond certain blacker lumps, which are, however, quite distinguishable from the mudstone; seen under the microscope the ash is found to be largely composed of a great variety of highly silicified lavas, some of which are vesicular.

Gelli-grin Calcareous Ash Series.

The Calcareous Ash Series of Gelli-grin is the most interesting series in the district, on account of its variable nature. It seems to be throughout its thickness a potential limestone, and to have pure limestones developed within it at different horizons in different places; these are all of a more or less lenticular character, appearing and dying out fairly rapidly. Thus, at Gelli-grin, above the Pont-y-Ceunant Ash, a thickness of about 40 feet of Calcareous Ash occurs with an ash-free mudstone-band near the middle, and above the Calcareous Ash is found the calcareous development so long regarded as the typical Bala Limestone, comprising 20 feet or so of massive and concretionary limestones overlain by alternating limestone and mudstone bands; these appear to lie wholly above the Calcareous Ash, being at once succeeded by the Rhiwlas Beds, of a totally different nature. This development is continued on Bryn-cut, on the opposite side of the Hirnant valley, but it changes when traced southwards. In the stream-section between Gelli-grin and Moel-fryn there is no trace of any limestone whatever, although calcareous ashy mudstones seem to be well developed; on Moel-fryn to the south the limestone reappears, but in the middle of the Calcareous Ash approximately at the horizon of the mudstone-band of the Gelli-grin section, while a considerable thickness of ashy mudstone at the top seems to represent the Gelli-grin Limestone. On Bryn Pig still farther south the development agrees in the main with that at Gelli-grin; but the limestone proper seems to extend rather higher up into the series, with a resultant greater thickness of crystalline limestone. On Creigiau Bychain there is no calcareous development at all, apart from the Calcareous Ash; but immediately south of Creigiau Bychain, in the stream at the foot of the hill, is another calcareous development—the Caerhafotty Limestone—at the very base of the Calcareous Ash. No further development of limestones of any thickness is found in the Calcareous Ash in the area here described, though a band about 2 feet thick of an ashy limestone has been worked for lime at Maes-meillion.

In addition to these impersistent limestones, there is a definite variation in the Calcareous Ash itself, when traced from north to

south; it is most conspicuously ashy in the north (Bryn-cut and Gelli-grin), and becomes less so towards the south, where ashy mudstones and calcareous mudstones take its place, although occasional intercalations of thin ashy bands among the mudstones seem to show that they really belong to the Calcareous Ash Series. When all the ashy material disappears, they are practically indistinguishable lithologically from the underlying Allt-Ddu Mudstones.

The Pont-y-Ceunant Ash at the base of this Calcareous Ash Series contains no fossils; but the remainder of the Series is richly fossiliferous, yielding many brachiopods and trilobites. Among the brachiopods *Orthis (Nicolella) actoniæ*, *Triplecia spiriferoides*, and *Plectambonites rhombica* are the most conspicuous; *O. actoniæ* occurs throughout, but is particularly characteristic of the limestone facies, while the *Triplecia* and *Plectambonites* abound in the more ashy beds. Among the trilobites *Trinucleus gibbifrons* and *Calymene caractaci* are common, and *Pterygometopus jukesii* is apparently characteristic of this horizon.

Fig. 2.—*Section up Bryn-cut. (Horizontal scale: 6 inches=1 mile.)*

1=Allt-Ddu Mudstones.
2=Pont-y-Ceunant Ash.
3=Gelli-Grin Calcareous Ash.
4=Gelli-Grin Limestone.
5=Rhiwlas Mudstone.

The limestone facies of this Ashy Series usually comprises one or more bands of massive or concretionary, dark grey-blue limestone, which is highly crystalline. It seems to be very pure, and has invariably been worked for lime in the past, kilns being associated with practically every outcrop. It sometimes contains small black phosphate-nodules, and at Y Garnedd is somewhat oolitic in character. It is usually a conspicuous feature in the landscape wherever it has been worked, since it shows up as a rock-wall in which the purer beds have a roughened outer surface; but the more thinly bedded portions show a definite honeycombed appearance on their weathered faces: this honeycomb weathering is also characteristic of the more calcareous portions of the Calcareous Ash itself, though there is little resemblance between the two rocks when freshly fractured.

Rhiwlas Mudstone and Limestone.

Following on the Gelli-grin Ashy Series come the Rhiwlas Beds, another mudstone series with impersistent limestones at its base. There is, however, a marked change in lithological character, whether limestone be developed or not: the characteristic beds are very fine pale-grey mudstones with some sandy mudstones, of so even a texture that they might be termed pasty; these are, as a rule, highly cleaved, and sometimes contain definite calcareous concretions. The coarser micaceous sandy beds which lie above them are less cleaved, but are still pale grey in colour. The base of these Rhiwlas Beds appears to be calcareous west of a north-and-south line running through Gelli-grin. There seems to be only one locality in the district where the Gelli-grin and Rhiwlas Beds are both calcareous, and this probably—in part, at any rate—accounts for the confusion that has existed in the past with regard to these beds, although they really differ conspicuously in fossil contents as well as in lithological character. The Rhiwlas Limestone is a pale-grey, minutely-lenticular, fragmentary limestone, and doubtless on this account is unsuitable for burning for lime: hence, unlike the limestones at the lower horizons, it has never been worked for that purpose. When weathered it presents much the same external appearance as the lower limestones, being characteristically honeycombed. It commonly occurs also in wall-like stretches varying from 10 to 15 feet in thickness, but never, so far as my knowledge goes, exceeding the latter thickness.

The characteristic fauna of these Rhiwlas Beds is the same, whether the limestone be developed or not, and a noteworthy feature is the almost total disappearance of all the large brachiopods which form so essential a part of the fauna of the Gelli-grin Beds. Certain small brachiopods occur; but it is the trilobite fauna that is the most conspicuous element, and the trilobites also are very different from those found in the lower beds, the most typical forms being *Phillipsinella parabola*, *Staurocephalus murchisoni*, *Cheirurus bimucronatus*, *Lichas laxatus*, large Illænids, and *Agnostus agnostiformis*. There is a relatively greater number of individuals in the limestone, but the fauna is the same in the pasty mudstone; it gradually dies out in the overlying beds, and has completely disappeared by the time that the Moel-fryn Beds have developed in force.

Moel-fryn Sandstones.

These sandstones, which are first seen merely as bands in the Rhiwlas Mudstones, become eventually massive, and occupy a considerable area of ground on Moel-fryn and on the hills north of the Hirnant valley beyond Aber Hirnant. They are a very monotonous and uninteresting set of beds, somewhat micaceous and of the same pale-grey colour throughout, without a trace of any fossils, so far as I have been able to discover.

Foel-y-Ddinas Mudstones.

Towards their upper limit the Moel-fryn Sandstones give place to rocks of more varied character: these are mudstones with large concretions, some fine-grained concretionary sandstones, and some bands of a peculiar rubbly rock, perhaps at one time calcareous, intercalated in the mudstone; their pale-grey colour is still characteristic, but these beds have yielded a definite fauna of small brachiopods and big trilobites (*Phacops mucronatus*).

Hirnant Beds.

These deposits are notably different in character from the beds below them, showing in fact a return, as regards the mudstones, to the darker blue-grey mudstone type of the Allt-Ddu Beds, but with a totally distinct fauna. The change takes place fairly rapidly, and, in the typical development as seen in the Hirnant valley near its head, the mudstones contain a remarkable pisolitic rock, the so-called Hirnant Limestone. This limestone has only a very local development, although the pisolitic mudstones associated with it are more widespread. These Hirnant Beds seem to change very rapidly along their strike; in place of the mudstones and the pisolitic limestone, a series of calcareous grits and purer quartzose grits occur, and this gritty character appears to become more pronounced northwards.

The highest mudstones seem to show the incoming of deeper-water conditions, as fine slaty shales which form good slate-bands come in, and, gradually increasing in importance, finally supersede all the mudstones. Purely slaty rocks succeed, in which trial-shafts have been made. These slates fall into two groups, a lower blacker, harder, and somewhat less banded group, in which Upper Birkhill graptolites have been found; and an upper softer group, with some lighter bands, yielding typical Tarannon graptolites.

IV. Details of Special Sections.

Nant Aber Derfel.

The nature of the Derfel Limestone and its relation to the *Dicranograptus* Shales have been described and mapped by Prof. W. G. Fearnsides, and, as he points out, the Derfel Limestone is best exposed in the gorge of the Nant Aber Derfel below the bridge carrying the old road from Arenig to Bala: here the shales above the limestone seem to be entirely without any trace of fossils; but out on the moor, above the bridge, when the stream is low, the shales intervening between the limestone and the Volcanic Series may be seen. They have yielded the following graptolites: *Dicellograptus sextans* (Hall), *Nemagraptus* sp., *Climacograptus schärenbergi* Lapworth, and *Cl. brevis* Elles & Wood. It is quite

likely that the graptolites *Dicranograptus rectus* Hopkinson and *Amplexograptus perexcavatus* Lapworth, found by Prof. Fearnsides in a loose block of shale on Mynydd Nodol, may have come from the same beds, since they, like the others, are characteristic fossils of the Upper Glenkiln Shales. The Derfel Limestone would, therefore, appear to be of Llandilian age; and, indeed, its fauna is a very remarkable one, since it is not of the type usually characteristic of the Welsh Llandilian, but approximates more closely to the fauna of the Scottish deposits of that age—more especially, perhaps, that of the Stinchar Limestone. The following are the more important forms:—

Lichas laxatus M'Coy.
Cybele verrucosa (Dalman).
Cybele rugosa (Portlock).
Illænus cf. *balclatchiensis* Reed.
Acidaspis hysterix Wyville Thomson.
Harpes flanagani Portlock.
Trinucleus sp.

Orthis (Platystrophia) biforata (Schlotheim).
Orthis (Nicolella) actoniæ (Sowerby).
Orthis (Hebertella) crispa (M'Coy).
Orthis alata Sowerby.
Orthis (Dalmanella) testudinaria var. *gracilis* Reed.
Orthis (Dalmanella) girvanensis (Davidson).
Orthis playfairi Reed.
Orthis (Heterorthis) confinis (Salter?).
Skenidium lewisi var. *craigense* Reed.
Triplecia craigensis Reed.
Clytonia andersoni Reed.
Clitambonites ascendens Pander?
Leptæna rhomboidalis Wilckens.
Rafinesquina expansa var.
Rafinesquina subarachnoidea Reed (?).
Stropheodonta corrugatella (Davidson).
Plectambonites llandeiloensis (Davidson).
Plectambonites sericea var. *semirugata* Reed.
Numerous Bryozoa and a few Crinoid-stems and Cystid-plates.

Nant Rhyd Wen.

Nant Rhyd Wen affords the best section in the Glyn-Gower Beds, up to their junction with the Frondderw Ash. The massively-bedded Glyn-Gower Sandstones are seen close to the junction of the stream with the Afon Glyn dipping 30° south-eastwards, and these occupy the bed of the stream for about 140 yards; then some soft shale-bands are occasionally seen alternating with the sandstones: one of the lowest yielded traces of graptolites (*Diplograpti*), including *Orthograptus truncatus* Lapworth, and other bands yielded *Trinucleus* of the *concentricus* type, *Glyptocrinus basalis*, and *Beyrichia*. These beds, which are now more sandy mudstones than sandstones, continue for another 300 yards until the stream makes a definite bend, and, instead of running northwestwards, turns nearly due north. At this point a low cliff on the right bank shows a section of some interest: at the top of the cliff the Frondderw Ash is seen, and at the bottom a good crystalline limestone, a few feet of sandy mudstone separating the two. The limestone appears to be merely a lenticle, for it dies away rapidly northwards and southwards, and is never more than 18 inches thick; it is, however, richly fossiliferous, the following

forms occurring, and *Orthis* (*Harknessella*) *vespertilio* being especially abundant:—

Orthis (Harknessella) vespertilio (Sowerby).
Dalmanella testudinaria (Dalman).
Dalmanella elegantula (Dalman).
Strophomena (Rafinesquina) expansa (Sowerby).
Plectambonites sericea (Sowerby).
Asaphus powisi Salter.
Calymene brevicapitata Portlock.
Calymene planimarginata Reed.
Homalonotus sp.
Trinucleus of the *concentricus* type (*gibbifrons* M'Coy ?).
Trinucleus sp. nov.
Encrinurus multisegmentatus (Portlock).
Monticulipora fibrosa (M'Coy).
Glyptocrinus basalis M'Coy.

The Frondderw Ash then comes down to the stream, and strikes along it for about 150 yards: it is here thinning out rapidly, and seems to be really two thin ash-bands separated by mudstones. As it leaves the bed of the stream to run up the opposite hillside a second limestone lenticle is seen—this time, however, above the ash, and with a quite different fauna from the other; in this gasteropods are especially abundant:—

Lophospira gyrogonia (M'Coy).
Bellerophon (Sinuites) bilobatus (Sowerby).
Murchisonia cf. *simplex* M'Coy.
Monticulipora fibrosa M'Coy.
Orthoceras vagans Salter.
Strophomena (Rafinesquina) expansa (Sowerby).
Orthis of the *calligramma* type.
Trinucleus of the *concentricus* type & sp. nov.
Glyptocrinus basalis M'Coy.

This limestone lies at the base of the Allt-Ddu Mudstones.

Y Garnedd.

Though the beds at Y Garnedd are much broken, yet the succession has features of especial interest, since some beds are better developed there than anywhere else in the district, and it is the locality where the Gelli-grin Limestone is definitely oolitic. Only the higher Caradocian Beds are seen; north of the main Llanderfel road the Allt-Ddu Mudstones are well exposed, and exhibit the usual bedding-surfaces densely covered with fossils. The following have been recognized south-west of Pandy-isaf:—

Orthis (Heterorthis) alternata (Sowerby) & var. *retrorsistria* (Davidson).
Orthis (Dalmanella) elegantula (Dalman).
Strophomena (Rafinesquina) expansa (Sowerby).
Plectambonites sericea (Sowerby).
Lingula ovata Sowerby.
Asaphus powisi Salter.
Trinucleus sp.
Glyptocrinus basalis M'Coy.
Beyrichia (Tetradella) complicata (M'Coy).
Orthograptus truncatus Lapworth & var. *pauperatus* Lapworth.

The higher beds of these Allt-Ddu Mudstones are seen on the south side of the road, and with the Pont-y-Ceunant Ash and the Gelli-grin Calcareous Ash are sharply folded, good exposures that reveal the structure being visible on or close to the track running between the Llanderfel and Lake-Vyrnwy roads; there is an almost continuous section of the Allt-Ddu Beds between the road and

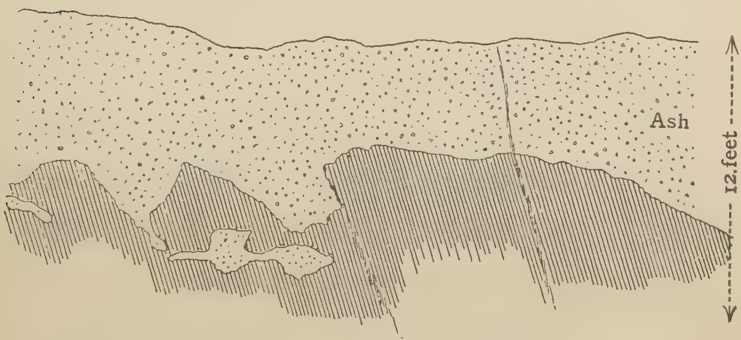
Y Garnedd Quarry, and at one point on the track about 100 yards north-east of the quarry an interesting calcareous bed is seen full of *Heterorthis alternata*, yielding in addition :—

Orthis (Heterorthis) alternata var. *retrorsistria* (Davidson).
Orthis (Dinorthis) flabellulum (Sowerby).
Orthis (s.s.) *calligramma* Dalman.
Plectambonites sericea (Sowerby).
Plectambonites transversalis (Dalman).
Leptæna rhomboidalis Wilckens.
Strophomena (Rafinesquina) expansa (Sowerby).
Glyptocrinus basalis M'Coy.
Beyrichia (Tetradella) complicata (M'Coy).

This bed when traced round exhibits the folding very well.

In Y Garnedd Quarry the relation of the Pont-y-Ceunant Ash to the underlying beds is clearly seen, the junction being remarkably irregular and 'pockety.'

Fig. 3.—*Y Garnedd Quarry: diagrammatic sketch illustrating the 'pockety' nature of the junction of the Pont-y-Ceunant Ash with the Allt-Ddu Mudstones.*



The Pont-y-Ceunant Ash itself contains no fossils, but the Gelligrin Calcareous Ash which overlies it is more or less fossiliferous throughout, particularly so in a band about 7 feet above the base. The following forms are all common :—

Orthis (Nicolella) actoniæ (Sowerby).
Orthis (Platystropha) biforata (Schlotheim).
Orthis (Dalmanella) elegantula (Dalman).
Orthis (Plectorthis) plicata (Sowerby).
Orthis (Dalmanella) testudinaria (Dalman).
Orthis (Harknessella) vespertilio (Sowerby).
Triplecia (Cliftonia) spiriferoides (M'Coy).
Leptæna rhomboidalis Wilckens.
Stropheodonta corrugatella (Davidson).
Plectambonites sericea (Sowerby).
Plectambonites transversalis (Dalman).
Plectambonites rhombica (Davidson).
Trinucleus concentricus Eaton.
Trinucleus gibbifrons M'Coy.
Calymene planimarginata Reed.
Calymene caractaci Salter.
Beyrichia complicata Salter.
Monticulipora lycoperdon (Say).
Monticulipora fibrosa (M'Coy).
Cystid-plates.
Primitia.
Palæarca sp.

On the east side of the track which runs between the Llanderfel and Lake-Vyrnwy roads east of Y Garnedd farmhouse, the trend of the beds is practically at right angles to that of those on the west side, against which they are obviously faulted. The Gelli-grin Limestone has here an extensive outcrop, since it appears to be just rolling over; it has, as usual, been quarried for lime, and has yielded the following fossils:—

Orthis (Nicolella) actoniæ (Sowerby).
Orthis (Plectorthis) plicata (Sowerby).
Orthis (Dalmanella) elegantula type.
Orthis (Dalmanella) testudinaria type.
Triplecia (Cliftonia) spiriferoides (M'Coy).
Plectambonites sericea (Sowerby).
Calymene caractaci Salter.
Chasmops macroura (Sjögren).
Monticulipora fibrosa (M'Coy).

Under the microscope the limestone is seen to be definitely oolitic: this character is, however, only visible in hand-specimens when they have been very much weathered. Underlying the limestone the Calcareous Ash may be detected; but it is not well exposed, although the Pont-y-Ceunant Ash shows up beautifully on a good dip-slope with the Allt-Ddu Mudstones underneath it.

The Gelli-grin Limestone is also seen again near an old limekiln on the north-east, nearer the river, with the lower beds beneath it a little farther north: the relation between these two sets of beds is rather obscure, but is suggestive of tear-faulting, with the tear running east and west.

The limestone is also apparently faulted westwards against the Allt-Ddu Beds, which are overlain by the Pont-y-Ceunant Ash and the Calcareous Ash, all three forming part of a small syncline.

Bryn-cut and Gelli-grin.

Part of the succession is clearly seen on the slopes of Bryn-cut, although the outcrops of the different beds are shifted in places by a series of tear-faults. The lower part of the hill on the north side is occupied by the Allt-Ddu Mudstones, highly cleaved as usual, except in a few harder more sandy bands: these slightly harder beds make two well-defined little scarps of which the lower is the more conspicuous (fig. 2, p. 142). Fossils occur throughout, commonest forms being the following:—

Orthis (Heterorthis) alternata (Sowerby) & var. *retrorsistria* (Davidson).
Orthis (Dinorthis) flabellulum (Sowerby).
Plectambonites sericea (Sowerby).
Strophomena (Rafinesquina) expansa (Sowerby).
Strophomena (R.) grandis (Sowerby).
Trinucleus gibbifrons M'Coy.
Trinucleus concentricus Eaton.
Asaphus powisi Salter.
Calymene caractaci Salter.

A short distance above the upper of the two scarps in the mudstones, another feature is formed by the Pont-y-Ceunant Ash, here about 25 feet thick; and about 50 feet of rock separate the ash

from the limestone outcrop, which in places is practically vertical. The Gelli-grin Limestone is here particularly pure, and has yielded only a few fossils:—

Orthis (Nicolella) actoniæ (Sowerby).
Orthis (Dalmanella) elegantula var.
Orthis (Platystrophia) biforata (Schlotheim).
Strophomena (Rafinesquina) expansa var.
Christiania tenuicincta (M'Coy).
Hyattella portlockiana (Davidson).
Lingula ovata Salter.
Monticuliporids.

The base of the limestone is a massive, blue-grey, crystalline rock; but it becomes more concretionary towards the top, and is immediately overlain by the pale-grey pasty Rhiwlas Mudstone, which close to Plas-Rhiwaedog contains:—

Encrinurus sexcostatus Salter.
Cybele verrucosa (Dalman).
Illænus davisi Salter.
Cheirurus sp.
Lichas sp.
Staurocephalus murchisoni Barrande.
Trinucleus sp.
Orthis (Dalmanella) elegantula var. *drummuckensis* Reed ?
Orthis (Hebertella) crispa (M'Coy).
Cystid-plates.
Primitia.

Most of the beds seen on Bryn-cut are also visible on the Lake-Vyrnwy road, with the exception of the Gelli-grin Limestone, which has been faulted out; on the other side of the valley the rocks sweep up and round to the classic locality of Gelli-grin, where the Allt-Ddu Beds and all the members of the Gelli-grin Ash Series are well seen. Just as on Bryn-cut, small scarps mark the position of the harder beds; but here it is the Pont-y-Ceunant Ash that makes the most definite feature, forming a low wooded ridge, easily detected at the lower level on the north side of the hill where it has been shifted by a tear-fault. The flatter open ground above is occupied by the Calcareous Ash, which has a well-marked mudstone-band near the middle of its course, and above again a steep cliff-like rise marks the position of the famous Gelli-grin Limestone (Bala Limestone). In places this is a very massive and highly crystalline rock, but elsewhere it consists of large concretionary masses running together, considerable variation in this respect being noticeable in the different quarries along the outcrop. Upwards, however, both the more massive and the more concretionary types pass over into thin bands of small concretions, grading up into regularly-bedded, highly-calcareous mudstones with a few bands of limestone, the total thickness not exceeding 25 feet. The concretionary and massive types of the limestone weather to a somewhat rough texture, with a conspicuous rusty-red colour; while the less massive upper beds show weathering of the honeycomb type. Immediately above, and continuing the sharp rise of the hill, are seen the pasty Rhiwlas Mudstones (fig. 5, p. 154). The most fossiliferous parts of the limestone appear to be in the quarry lying west of Gelli-grin farmhouse, and along the cliff-face west-south-west of the farm, this last being the exposure recorded by Jukes. The fossils noted are as follows:—

Orthis (Plectorthis) plicata (Sowerby).
Orthis (Plæsiomys) porcata (Sowerby).
Orthis (Nicolella) actoniæ (Sowerby).
Orthis (Dalmanella) elegantula var.
Orthis (Dalmanella) testudinaria var.
Orthis unguis Sowerby.
Leptæna rhomboidalis Wilckens.
Plectambonites sericea (Sowerby).
Plectambonites rhombica (Davidson).
Lingula ovata Sowerby.
Pterygometopus jukesi (Salter).
Cybele sp.
Trinucleus concentricus Eaton.
Beyrichia (Tetradella) complicata (M'Coy).
Monticulipora fibrosa (M'Coy).
Monticulipora lycoperdon (Say).
Monticulipora lens (M'Coy).
Cystid-plates.

A good section of the upper beds is displayed along an old cart-track leading to the moor: this track runs at first across the strike, and the Gelli-grin Calcareous Ash with the limestone above it is seen dipping at 30° along the track. Just where the track bends round so as to run at right angles to its former direction for a short distance, it runs parallel with the junction of the limestone and the Rhiwlas Beds, which may be clearly seen on the south side resting upon the limestone; while higher beds are exposed still farther along the track after it has resumed its original trend. These Rhiwlas Mudstones contain:—

Phillipsinella parabola Barrande.
Lichas laxatus M'Coy.
Encrinurus sexcostatus Salter.
Agnostus agnostiformis (M'Coy).
Remopleurides colbii Portlock.
Remopleurides sp.
Staurocephalus murchisoni Barrande.
Illænus davisi Salter.
Trinucleus sp.
Cheirurus bimucronatus Murchison.
Plumulites peachi (N. Etheridge).
Orthis (Hebertella) crispa (M'Coy).
Plectambonites quinquecostata (M'Coy).
Stropheodonta corrugatella (Davidson).
Christiania tenuicincta (M'Coy).
Skenidium sp.
Very small Ostracods.

Traced southwards the limestone is seen to bend sharply round slightly above a little fir-copse, where the main road divides into two, and this change in strike is very obvious in a good exposure close to the lower of the two roads. The Pont-y-Ceunant Ash also exhibits this folding, but part of its outcrop is faulted off.

The course of the limestone is marked by dense vegetation, so that when, as the result of the tear-faulting, the ash is brought against the limestone there is little to distinguish the two in this respect; the feature due to the limestone dies away before Yspydd-adog is reached, and not a trace of it is to be found in the streams between Gelli-grin and the Moel-fryn quarries.

Moel-fryn.[1]

The sections seen in the Moel-fryn quarries are particularly interesting: the ashy material, as a whole, is very much less conspicuous than at Gelli-grin; no definite band of ash occurs at the base, but there is a correspondingly greater thickness of cleaved ashy mudstones and calcareous ashes, suggesting that the Pont-y-

[1] Probably Bryn-melyn of the old Geological Survey lists.

Fig. 4.—*Detail of Long Quarry-face, Moel-fryn. (Vertical scale: 1 inch = 4½ feet.)*

Ceunant Ash has become merged in the Calcareous Ash Series, which is extremely fossiliferous throughout. The limestone, on the other hand, is well-developed, although it is at a different horizon from the limestone of Gelli-grin, being in the middle of the Calcareous Ash Series (fig. 6, p. 154). This limestone makes a definite feature as soon as it crops out, and is first seen just a little below the moor wall; here it is much bent about, striking north-east and south-west, north and south, and east and west in rapid succession. A lower feature on the hill seems to mark the base of the Calcareous Ash Series, and the Allt-Ddu Mudstones are seen below, all these rocks being then abruptly cut off by the Moel-fryn displacement which runs across the whole country.

The face of the long quarry shows an excellent section (fig. 4) with the massive limestones at the bottom overlain by cleaved ashy mudstones, and at the top a distinct band of coarse ash, at least 1 foot thick. Above this band of ash there is about 20 feet of calcareous ashy mudstone, and immediately above this, at the southern end of the exposure, are seen Rhiwlas Beds of the pasty mudstone type, while a little farther out on the moor the higher

beds of the Rhiwlas Series may be noted. The fossils from the Calcareous Ash include the following:—

Orthis (Harknessella) vespertilio (Sowerby).
Orthis (Plectorthis) plicata (Sowerby).
Orthis (Plæsiomys) porcata (Sowerby).
Orthis (Dalmanella) elegantula var. *parva* Reed.
Orthis (Dalmanella) testudinaria (Davidson).
Orthis (s.s.) calligramma Davidson.
Orthis (Platystrophia) biforata (Schlotheim).
Orthis (Nicolella) actoniæ (Sowerby).
Triplecia (Cliftonia) spiriferoides (M'Coy).
Leptæna rhomboidalis Wilckens.
Plectambonites sericea (Sowerby).
Plectambonites rhombica (Davidson).
Plectambonites transversalis (Dalman).
Strophomena deltoidea Conrad.
Trinucleus concentricus Eaton.
Trinucleus gibbifrons M'Coy.
Calymene caractaci Salter.
Pterygometopus jukesi (Salter).
Acaste apiculata (Salter).
Lichas laxatus M'Coy.
Beyrichia complicata M'Coy.
Monticulipora lycoperdon (Say).
Monticulipora fibrosa (M'Coy).

The fauna of the limestone appears to be much the same, although, on the whole, individuals are not so numerous.

Bryn-pig.[1]

The chief interest of the Bryn-pig exposures is the occurrence of the calcareous facies of both the Rhiwlas Beds and the Gelligrin Calcareous Ash Series in the same section, proving clearly (if proof be needed) that on lithological grounds alone, apart from any palæontological considerations, it is possible to discriminate between the old so-called Bala Limestone and the Rhiwlas Limestone.

The main exposure is that forming a more or less sheer cliff-face on the south-eastern flank of Bryn-pig, where the beds are seen forming part of a syncline obliquely faulted through its centre.

The lower of the two limestones is here especially well-developed, and is a beautiful, highly crystalline, dark blue-grey rock, which on the north side of the hill is much veined with both quartz and calcite, the presence of the quartz being due apparently to the proximity of a fault along which there has been much quartz mineralization. All along this north side of the hill the lower rock has been extensively quarried for lime; about 1 foot of Calcareous Ash and 4 feet of pasty Rhiwlas Mudstone separate it from the lowest stratum of calcareous Rhiwlas Beds—that is, the Rhiwlas Limestone. This limestone, as developed here, is neither so crystalline in character nor so massive as in some of the more westerly exposures (Creigiau Bychain), but is still definitely a limestone; towards the top the calcareous bands are separated by bands of the pasty Rhiwlas Mudstone, which show up well on the weathered surface by virtue of their cleavage: if we reckon all these with the main limestone-band (about 6 feet thick), the calcareous development of the Rhiwlas Series may be estimated as having a thickness of 12 feet, and the occurrence of abundant small phos-

[1] Probably Bryn-bedwog of the old Geological Survey lists.

phate nodules in it is characteristic. The fossils from this locality include:—

Phillipsinella parabola Barrande.
Agnostus agnostiformis (M'Coy).
Encrinurus sexcostatus Salter.
Staurocephalus murchisoni Barrande.
Lichas sp.
Illænus davisi Salter.
Cheirurus bimucronatus Murchison.
Trinucleus sp.
Orthis (Nicolella) actoniæ var. *asteroidea* Reed.
Christiania tenuicincta (M'Coy).
Orthis (Hebertella) crispa (M'Coy).
Orthis elegantula, var. *drummuckensis* Reed.
Hemicosmites sp.
Echinosphærites arachnoideus Salter.

Above this are seen at least 20 feet of pasty Rhiwlas Mudstone, so that the faunal succession compares well with that observed at Gelli-grin. (See figs. 5 & 7, p. 154.)

As we pass round the syncline to the west it becomes obvious that both limestones are abruptly cut off, and their place taken in the line of strike by the fossiliferous Calcareous Ash, the outcrop of the Gelli-grin Limestone being shifted into the line of the Rhiwlas Mudstones. Thus, the syncline, as seen so far, is affected by cross-faulting with a downthrow to the north, the result being that on the south the Gelli-grin Limestone is practically folded on itself, the merest tongue of pasty Rhiwlas Mudstone occupying the centre of the fold; this limestone is not well exposed at the present time, but a double line of workings indicates its outcrop. Oddly enough, the outcrop of the limestone is almost continuous on the south-east side of the fold despite the fault, and both outcrops are truncated by the Moel-fryn displacement. The small dislocation east of the fold has the effect of diminishing the outcrop of the Calcareous Ash, and brings the Gelli-grin Limestone very close upon the Allt-Ddu Mudstones.

Another small outcrop of limestone seems to belong to another fold, while a highly contorted outcrop lying south of this and east of the main outcrop is so affected by the great line of disturbance in its immediate neighbourhood that some of the associated mudstones are practically schists. At this locality, probably on account of the lenticular nature of the Gelli-grin Limestone, there is a rather greater thickness of rock separating the two limestones, a foot and a half of Calcareous Mudstones, 4 feet of Calcareous Ash, and 4 feet of pasty Rhiwlas Mudstone being clearly visible above the main limestone and below the calcareous development of the Rhiwlas (fig. 7, p. 154). At this locality the lower limestone is richly fossiliferous, and has yielded the following species:—

Orthis (Nicolella) actoniæ (Sowerby).
Strophomena (Rafinesquina) expansa (Sowerby).
Plectambonites sericea (Sowerby).
Calymene sp.

Creigiau Bychain.

The group of synclines on Creigiau Bychain shows an excellent series of exposures of the calcareous development of the Rhiwlas Beds, with a maximum thickness of 12 feet; occasionally the beds are calcareous right down to their junction with the Calcareous Ash, in other places there is a definite band of pasty mudstone

Vertical sections showing the variation in the Gelli-grin Calcareous Ash.
(Vertical scale : 1 inch=45 feet.)

Fig. 5.

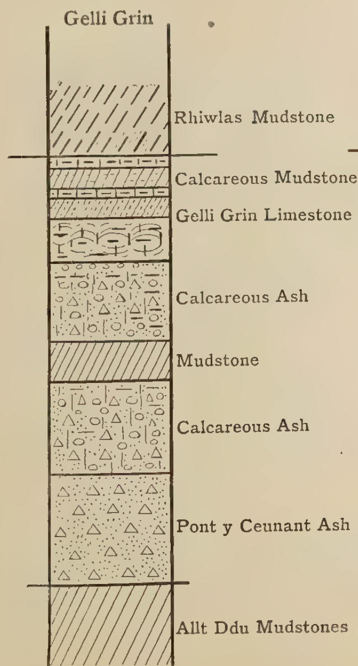


Fig. 6.

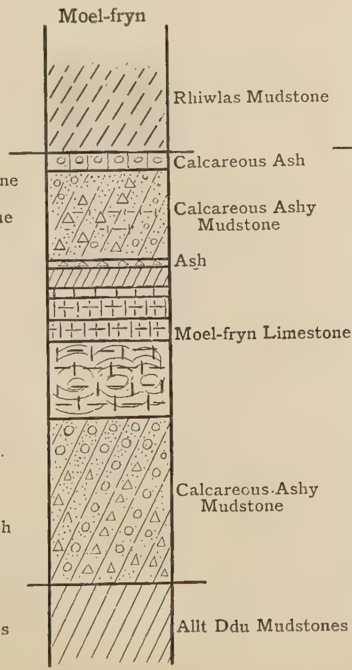
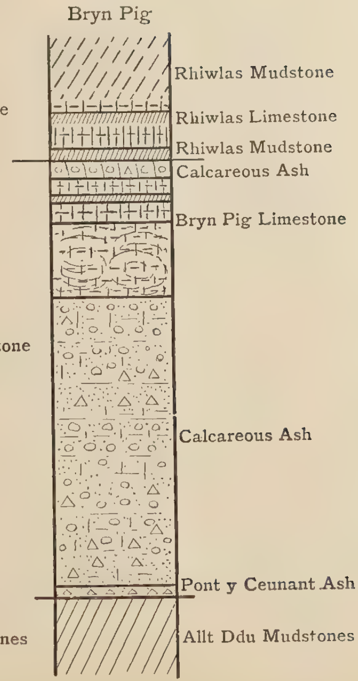


Fig. 7.



intervening between the two. The limestone shows up best on the scarp-face, and then forms a wall-like mass weathering in honeycomb fashion, and recalling in many respects the less massive part of the Gelli-grin Limestone as regards outward appearance. Compared with the lower limestone, however, the Rhiwlas is always, as already stated, paler in colour, less pure, minutely lenticular, and more fragmentary, characteristics which probably account for its rejection for burning to lime, while the Gelli-grin and other limestones of the Calcareous Ash Series have invariably been utilized in this respect. Highly calcareous mudstone-bands are intercalated in the Rhiwlas Limestone, and some of these, as also the purer more crystalline limestone-bands, contain phosphate-nodules which vary in size, the biggest found on Creigiau Bychain being about the size and shape of a blackbird's egg.

The greatest of the synclines presents a definitely ovoid outline, its axis trending practically north and south, and having a gentle southward pitch, the general shape of the fold being clearly indicated by the wall-like outcrop of the Rhiwlas Limestone. A second minute fold occurs immediately north-east of this, in which the Rhiwlas Limestone is bent upon itself at the top of a little roll-over of the Calcareous Ash; farther north-westwards another almost complete syncline in the limestone is seen, and a fragment of the same rock indicates its connexion with another similar pitching fold still farther north-westwards.

The Rhiwlas Limestone of the greatest syncline has yielded the following fossils :—

Encrinurus sexcostatus Salter.
Agnostus agnostiformis (M'Coy).
Illænus davisi Salter.
Phacops sp.
Christiania tenuicincta (M'Coy).
Hyatella portlockiana (Davidson).
Plectambonites transversalis (Dalman).
Echinosphærites stellulifera Salter.
Glyptocrinus basalis M'Coy.

While the Calcareous Ash immediately beneath is still more richly fossiliferous, yielding :—

Calymene caractaci Salter.
Chasmops conicophthalmus (Boeck).
Trinucleus gibbifrons M'Coy.
Trinucleus excentricus Eaton.
Homalonotus bisulcatus Salter.
Strophomena (Rafinesquina) expansa (Sowerby).
Orthis (Nicolella) actoniæ (Sowerby).
Orthis (Dalmanella) testudinaria var.
Triplecia (Cliftonia) spiriferoides (M'Coy).
Plectambonites rhombica (Davidson).
Plectambonites sericea (Sowerby).
Plectambonites quinquecostata (M'Coy).
Leptæna rhomboidalis Wilckens.
Glyptocrinus basalis M'Coy.
Monticulipora fibrosa (M'Coy).
Holopella sp.
Bellerophon (Oxydiscus) acutus (Sowerby).

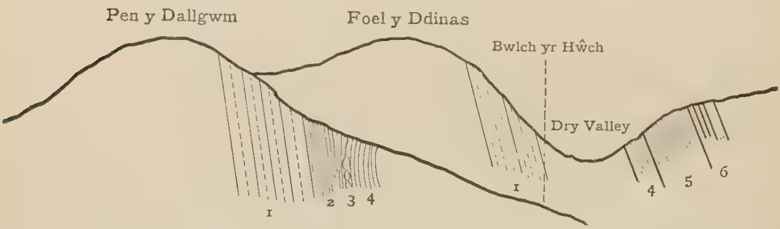
Cwm-yr-Aethnen, Pen-y-Dallgwm, and Foel-y-Ddinas.

These places together afford a good section of the highest beds of the Ashgillian and overlying Silurian rocks.

The Moel-fryn Sandstones, as already described, are very monotonous pale-grey rocks, with some intercalations of mudstones

towards the top; they form the steep-sided valley of the Hirnant below Bwlch-yr-Hŵch and the whole of the precipitous Dallgwm, where they are seen dipping eastwards at increasingly higher angles. They occupy the greater part of Bwlch-yr-Hŵch itself; but, at its south-eastern end, it is obvious from the change in the scenery that the rocks alter in character, and this alteration coincides with the beginning of the Foel-y-Ddinas Mudstones. These beds are, in the main, highly-cleaved pale-grey mudstones, but comprise some of a rubbly concretionary nature, which weather in a very characteristic manner; all dip eastwards at angles from 60° to 70°, and appear to contain fossils throughout, although the fauna is not a rich one, the most noteworthy feature being the presence of *Phacops mucronatus* Brongniart, the remainder being chiefly small brachiopods, such as *Atrypa marginalis* Dalman,

Fig. 8.—*Sketch looking northwards, showing the Hirnant Beds and their relation to the Silurian. (Horizontal scale: 6 inches=1 mile.)*



1=Foel-y-Ddinas Beds.
2=Hirnant Mudstones below Hirnant Limestone.
3=Hirnant Limestone.
4=Hirnant Mudstones above Hirnant Limestone.
5 & 6=Graptolitic shales yielding graptolites indicative of the zones of *Monograptus sedgwicki* and *M. crispus*.

Orthis (Dalmanella) elegantula (Dalman), *Skenidium* sp., and *Platystrophia biforata* var. *fissicostata* (Davidson). These deposits are succeeded by the Hirnant Beds, dark-blue mudstones of much softer nature, which yield far more readily to weathering than the beds beneath them: they dip at a still higher angle, 70° to 80°, being (as it were) plastered on the east side of Pen-y-Dallgwm. They seem to occupy the head of the Hirnant valley (Cwm Hirnant), and the line of the old high-level valley east of Foel-y-Ddinas; but a small tear separates the two. On Pen-y-Dallgwm, due west of the shepherd's house in Cwm-yr-Aethnen, there is still to be seen the old classic section in which the famous pisolitic facies of the Hirnant Limestone occurs. This is exposed in an old quarry on the hillside, to which an old grass-track still leads from the main Lake-Vyrnwy road. The following succession can be made out there:—

	Thickness in feet.
(1) Fossiliferous blue-grey mudstone, full of fossils	12
(2) Pisolitic limestone in large concretionary masses measuring 3 × 2 feet	3
(3) Concretionary calcareous mudstone, almost a limestone in places, and with numerous scattered pisolitic grains; blue-grey when fresh, but weathering to a dirty cream-colour ...	10
(4) Dark bluish mudstone, with a few scattered pisolitic grains, and but few fossils	10

[The total thickness of these rocks, as seen in the quarry, is from 25 to 30 feet.]

The same characteristic fossils occur throughout:—

Orthis hirnantensis M'Coy.
Orthis sagittifera Davidson.
Dalmanella elegantula (Dalman).
Strophomena siluriana Davidson.
Platystrophia biforata (Schlotheim).
Monticulipora fibrosa (M'Coy).

The pisolitic limestone has been so well described by Fulcher that no further description need be given, although the pisolitic grains which he defines as ellipsoidal in form are only so in the direction of the cleavage.

On the opposite side of the Hirnant several small slate-trials have been made; beneath the lowest of these mudstones similar to those last described are seen dipping into the hill at 75°, and these pass upwards into a similar rock but containing slaty bands. In all these the Hirnant fauna is to be found (fig. 8). The slate-bands increase steadily in importance, and without any break the Hirnant Beds pass over into a slate series to which I have given the name Cwm-yr-Aethnen Beds: these appear to be about 350 feet thick. They are, however, capable of a twofold grouping, both on lithological and on palæontological grounds: the lower group (150 feet) consists of hard, fine, blue-grey slates with some banding, yielding Upper Birkhill graptolites:—*Monograptus sedgwicki* (Portlock), *Climacograptus scalaris* (Hisinger), *Orthograptus bellulus* (Törnquist), *Glyptograptus serratus* Elles & Wood, and *Petalograptus* sp., a fairly typical assemblage of the Zone of *M. sedgwicki*. These pass up into somewhat softer slates, more definitely banded in lighter tones than the lower group, and yielding well-preserved graptolites in the blacker bands:—

Monograptus crispus (Barrande).
Monograptus turriculatus (Barrande).
Monograptus priodon Brown.
Monograptus nudus Lapworth.
Monograptus discus Törnquist.
Monograptus becki Barrande.
Monograptus marri Perner.

V. Structure of the District.

The structure of the district is somewhat complicated, although when the main principles underlying the general plan are understood it appears less complex than might be thought at first sight.

The interpretation here given, which seems to accord with the facts now observed, necessitates a modification of the views hitherto

published regarding the nature of the Bala Fault; this line of disturbance has been held by Jukes, Ramsay, and others to be a normal fault with a maximum downthrow to the north-west of about 11,000 feet. The nature of this displacement appears to be distinctly more complex when viewed in the light of completer knowledge, and instead of being continuous with the Dee-Valley Fault in the manner shown on the 1-inch Geological Survey Map and accepted by Sir Aubrey Strahan,[1] it runs up into the country north of the lake; there it appears to have been profoundly affected by later post-Carboniferous movements. The evidence in the district as a whole clearly points, however, to its having been initiated as an important structural line in connexion with the Caledonian System of folding.

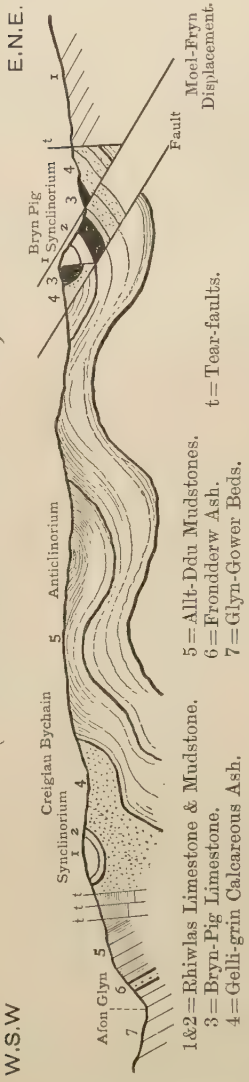


Fig. 9.—*Section from Creigiau Bychain to Bryn-pig, to illustrate the folding.* (*Horizontal scale: 4 inches = 1 mile.*)

1&2 = Rhiwlas Limestone & Mudstone. 3 = Bryn-Pig Limestone. 4 = Gelli-grin Calcareous Ash. 5 = Allt-Ddu Mudstones. 6 = Frondderw Ash. 7 = Glyn-Gower Beds. t = Tear-faults.

The Bala district forms part of the southern limit of the great **S**-shaped buckle of rocks round the Harlech Dome, so beautifully brought out by the outcrop of the volcanic rocks[2]; the trend-lines are in the main those of the Caledonian System of folds modified by local circumstances, the modification in this case being primarily due to the presence of the Harlech Dome.

The whole country may be regarded as folded round and against the Harlech Dome by pressure acting from a general south-easterly direction: thus, in the area here described, the primary folding appears to follow north-east and south-west trend-lines in those parts of the district north and south where the rocks escape more or less from the influence of the Harlech Dome; but in the intervening area where that influence is fully felt, the axes of the folds run approximately north and south. Nevertheless, it is the north-

[1] Pres. Address to Sect. C. Rep. Brit. Assoc. (Cambridge) 1904, p. 535.

[2] Geological Survey of England & Wales ¼-inch maps: New Edition, Sheets 9 & 10.

east and south-west trend-lines of the volcanic masses of the Arans and Arenig Bach that appear to control the trend of the thrust-planes, the rocks above the volcanics being apparently thrust over the more resisting volcanic rocks underneath; hence the major lines of displacement have a general north-east and south-west trend, and in the central area cross the lines of folding obliquely. The differential resistance to the thrusting force in different parts of the thrust-masses shows itself in the development of numerous tear-faults. The facts seem to indicate that the rocks must first have been thrown into a series of major folds with minor folds and ripples, the trend of which at the present time varies in different parts of the area between north-east and south-west and north and south, with a gentle southward pitch (fig. 9). Among these folds were developed an important anticline and syncline trending parallel to the line of the Central Wales Syncline; as pressure continued, the folds as a whole were packed with increasing closeness against the Harlech Dome, and, the resistance of the volcanic belt becoming more pronounced, the anticline gave way, and its south-eastern limb was driven over on to the syncline by means of a series of compressional faults, of which the Bala Fault is one. The existence of this synclinal fold is still indicated in the westward dips of the rocks along the north-western shore of the lake: as, for example, where the Frondderw Ash is brought up again half a mile south-west of Llan-y-cil, farther south 1 mile and 1½ miles south-west of Llanwchllyn, and perhaps still more clearly north of the lake north-west of Moel-Emoel, where the apex of the fold, much torn by faults, is distinctly visible with the line of the Bala Fault lying to the east of it. Simultaneously with this squeezing-out of the anticline and the further packing or thrusting on to the Harlech Dome, owing to the unequal resistance of different portions of the thrust-masses there were developed the striking series of tear-faults which are so marked a feature of the district.

That these really are tear-faults and not merely normal faults, as they were regarded by the earlier workers on this ground, is clear from the horizontal displacement of the beds affected, which is entirely irrespective of the amount of dip.

The country appears to be affected by the following major lines of displacement (fig. 1, p. 136):—

(1) **The Llyn-Tegid Line.**
(2) **The Bala-Lake Line.**
(3) **The Llangower Line.**
(4) **The Cefn-ddwy-graig Line.**
(5) **The Moel-fryn Line.**
(6) **The Ffrîdd Defaid Line.**

There is almost certainly at least one other line to the north-west within the *Dicranograptus* Shales; but this unfortunately I have been unable to map, owing to the nature of the ground and the character of the rocks occupying it: for the black shales afford no evidence of their age, and the lines of break that can be seen in the section visible in the Nant-Hir cannot be traced for

any distance across the dense grass- or heather-covered moorland. The differential movements of the rocks, however, seem to necessitate the existence of such lines.

The Llyn-Tegid Line was first noticed by P. Lake (Fault B)[1] as running along the north-western shore of the lake; it seems to emerge at the northern end of Bala Lake, and, acquiring a slightly more northerly trend, runs up to the Nant-Hafhesp valley, being then apparently bent round into one of the east-north-east and west-south-west lines of displacement of the Moel-Emoel area. Its chief effect is to cause concealment of portions of the higher beds, so far as the northern part of the district is concerned. It appears to be more affected by the topography than the Bala-Lake Fault and, therefore, is probably of lower inclination.

The Bala-Lake Line is a more important displacement; it seems to run fairly near the south-eastern shore-line of the lake, probably just outside the Llangower peninsula, and, emerging at the northern end of the lake, runs up into the high ground on the north approximating to the line of the Nant Cwm-da. Everywhere along it the rocks on its south-eastern side are driven over those on the north-west; in the extreme south the volcanic rocks forming Aran Ben Llyn and the beds beneath them are brought over the *Dicranograptus* Shales, while farther north the Caradocian beds are thrust over the Ashgillian in all the country north of the lake as far as Moel-Emoel. Its inclination is fairly high.

The Llangower Displacement, with the subsidiary Cefn-ddwy-graig branch, is perhaps the most striking thrust-line of the district; for there has been considerable differential movement of the rocks above this Llangower thrust, and consequently a great development of tear-faults is associated with it, especially in the area between Llangower and Mynydd Cefn-ddwy-graig, where the structure of the country is clearly brought out by the outcrops of the Frondderw Ash. The tearing becomes definitely less with the development of the Cefn-ddwy-graig Displacement, which seems to have effected compensation 'en bloc.' The beds, however, above this line of thrust are very sharply faulted and folded near Pont-y-Ceunant, where the Llangower, Cefn-ddwy-graig, and Moel-fryn lines all come closer together; the rocks above the Cefn-ddwy-graig thrust and beneath that of Moel-fryn show a series of small subsidiary thrusts affecting the anticlinal lines of the small folds so as to bring about an effect of imbrication, and this, combined with tearing, has shattered the rocks to pieces.

The chief effect of the Llangower thrust is to bring the lower beds of the Allt-Ddu Mudstones, close to their junction with the Frondderw Ash, over the higher Allt-Ddu Mudstones; while along the Cefn-ddwy-graig line the Glyn-Gower Sandstones, the Frondderw Ash, and the Lower Allt-Ddu Mudstones are all in turn

[1] Geol. Mag. 1900, p. 212.

brought over the higher Allt-Ddu Beds. The Llangower thrust, as seen in section near Llangower, has an inclination of about 40° south-eastwards, and close to the point where it branches off from this line the inclination of the Cefn-ddwy-graig thrust appears to be similar, but farther north its inclination becomes definitely lower and more affected by the topography. At Pont-y-Ceunant, despite the shattering of the rocks associated with it, the main effect is the concealment of some of the Allt-Ddu Mudstones.

The Moel-fryn Displacement is a very extensive fault, bringing about displacement of the rocks along a line which extends completely across the area mapped; it is responsible for much discontinuity in the beds of the Gelli-grin Calcareous Ash Series, these being often faulted out, together with parts of the Allt-Ddu Mudstones and the Rhiwlas Beds. The packing along this line is, however, decidedly less than along the Llangower displacement, and the inclination of the fault-plane seems to be at a lower angle; tearing is not a characteristic feature of the rocks above it, except at the northern end of the district, where it is comparatively slight as at Gelli-grin or on Bryn-cut.

The Ffrîdd Defaid Line has been traced for only a short distance: it appears to cause concealment of some of the Lower Ashgillian Beds, and is very clearly indicated on the north side of the Hirnant valley; but on the south the country is at first heavily wooded and then merges into the open moor, where exposures are so few and far between that it is no longer possible to trace the displacement.

There seems to be fairly definite evidence of the decrease in the importance of the displacements east of Bala Lake, and this is continued still farther eastwards, where along the line of the Hirnant valley, at the source of that stream, the beds merely plunge down steeply without any break, the softer slates being apparently squeezed between the Denbigh Grits and Flags on the one hand and the hard Moel-fryn Sandstones on the other. All the major lines of displacement can be traced fairly easily across country, since they are generally marked by a feature in the landscape, this being, however, occasionally emphasized by the nature of the rocks affected; thus, the Llangower thrust is marked by a well-defined fault-scarp, which is more pronounced when the harder Glyn-Gower Sandstones are brought against the Allt-Ddu Mudstones.

A smaller but clearly defined scarp also marks the line of the Cefn-ddwy-graig thrust; on the other hand, the Moel-fryn line is more usually indicated by a depression, as it is on the pass separating the valleys of the Dwynant and the Afon Glyn.

The tear-faults associated with the major lines of displacement deserve mention. The most conspicuous are those associated with the Llangower thrust: of these, the Ty'n-y-mûr and Ty'n-y-twll tears both effect a very noteworthy shift of the Fronddérw Ash,

while the Bryniau-goleu tear shifts the same bed when practically vertical for a distance of half a mile; the Beudy-Graienyn tear is the last of the big tears to bring about a noticeable horizontal movement of the beds. That all have probably been shifted to some extent is, nevertheless, suggested by the outcrop of the Frondderw Ash between the two main outcrops north-east of Cornelau farm; this can only be interpreted as implying a wholesale shortening of the line by differential movement north-westwards.

The tear-faults associated with the Moel-fryn displacement are less important, although there is an interesting little group of them on Bryn-cut, north of the Hirnant valley, where the outcrops of the Gelli-grin Limestone and the Pont-y-Ceunant Ash are conspicuously shifted.

These tear-faults are also distinguished by definite topographical features, since they are nearly always marked by a gash limited by wall-like outcrops of the rock on each side, the width of the gash varying with the importance of the tear; they also are almost invariably accompanied by more or less horizontal slickensiding and by intense quartz mineralization.

VI. Palæontology.

There are certain features of interest in the faunas found at different horizons in the Bala district. In the first place, the fauna of the Derfel Limestone is a remarkable one, for, from the list given on p. 145, it will be seen that in its general character the fauna is more closely related to that of the Scottish rather than to that of the Welsh Llandilian rocks. Brachiopods are far more conspicuous than is usual in the Welsh Llandilian, and there seems to be no trace whatever of the trilobites which are of common occurrence in the Welsh beds of that age, such as *Trinucleus fimbriatus*, *Ampyx nudus*, *Ogygia buchi*, *Barrandia radians*, *B. cordai*, *Calymene duplicata*, and other forms, which even as near as Builth (Gwern-y-fed-fach) occur associated with the same graptolites as those that are found in Nant-Derfel.

Anyone who has studied the faunas of the Lower Ordovician rocks of Scotland must have realized that they are essentially the forerunners of the Ashgillian fauna, and some of the forms found in the Nant-Derfel gorge appear to be identical with some occurring in the Ashgillian itself. The occurrence, therefore, of this type of fauna at this horizon in this area is of great palæontological significance.

As respects the faunas of the Caradocian rocks, while the grouping here adopted is necessarily based mainly upon the assemblages found in the Bala country, the assemblages found in other parts of England and Wales have also been taken into consideration.

With regard to the general aspect of the Caradocian fauna, it may be noted that it is essentially a trilobite–brachiopod fauna. It is very generally rich in brachiopods of large size, many of

which, however, are not peculiar to it, but are long-ranged forms; though some, like *Heterorthis alternata* (Sowerby) and its variety *retrorsistria* (Davidson), appear to be characteristic Caradocian species. The trilobites, however, are more significant; *Calymene planimarginata* appears to range throughout, as do also *Homalonotus bisulcatus* and *Trinucleus concentricus*; others, though they may perhaps be found eventually all through the Series, are at any rate more abundant in either the lower or the higher beds. Thus, the large *Asaphus powisi* seems to be more particularly characteristic of the lower beds, as does also a form which agrees well with *Calymene brevicapitata* Portlock; on the other hand, species of *Chasmops*, *Pterygometopus jukesi*, *Calymene caractaci*, and *Acaste apiculata* are undoubtedly more abundant in the higher beds.

Monticuliporids are abundant, similar species ranging not only through the Series, but above and below its limits. *Glyptocrinus basalis* is everywhere a common fossil, but Cystid-plates are more numerous in the higher beds, although they seem to attain a still greater development in the basal beds of the Ashgillian.

Neither gastropods nor lamellibranchs, though locally present in fair abundance, form any important part of the fauna.

The most satisfactory palæontological classification, therefore, is that which groups trilobites and brachiopods together: the former because they afford the surer guides to age, the latter because they constitute so great a part of the fauna as a whole. On this basis the Caradocian rocks, as developed in the Bala country, may be regarded as belonging to the *Calymene-planimarginata* fauna.

Other fossils that range throughout in some abundance are:—

Trinucleus concentricus Eaton, or a variety.
Homalonotus bisulcatus Salter, or a variety.
Orthis (Platystrophia) biforata (Schlotheim).
Orthis (Harknessella) vespertilio (Sowerby).
Orthis calligramma Davidson.
Orthis (Dinorthis) flabellulum (Sowerby).
Plectambonites sericea (Sowerby).
Monticulipora fibrosa (M'Coy).

A further subdivision may be made into two sub-faunas: a lower one characterized by the abundant presence of *Asaphus powisi* and *Heterorthis alternata*, and an upper containing *Chasmops* and *Orthis* (*Nicolella*) *actoniæ*. The fossil assemblages characteristic of these two sub-faunas are recorded in the lists on pp. 170–71. The graptolites found are important, since they enable some definite comparison to be made as to the relative ages of the beds in the rocks of the 'shelly' type and 'graptolitic' type respectively.

The typical form of *Orthograptus truncatus* Lapworth has been found in the mudstones of the Glyn-Gower Beds (Pont-yr-Onen and Nant-Rhyd-Wen), and, so far as our present knowledge goes, that fossil is highly characteristic of the zone of *Dicranograptus clingani*, although towards the top of that zone and in the succeeding zone of *Pleurograptus linearis*, its place is gradually taken by the longer and thinner variety *pauperatus* Lapworth.

These two forms occur together near the top of the Allt-Ddu Mudstones (south-west of Pandy-isaf), so that it appears extremely probable that the Glyn-Gower Beds, together with the Allt-Ddu Mudstones, may be taken to represent the shallow-water equivalents of the zone of *Dicranograptus clingani*.

The general aspect of the Ashgillian fauna, as developed in the Bala district, is widely different from that of the Caradocian; though, unfortunately, only the Rhiwlas Beds at the base of that series and the Foel-y-Ddinas Beds at the top contain fossils. The most noticeable feature in the Rhiwlas Beds is the almost complete disappearance of all the big brachiopods which are so numerous, as regards both individuals and species, at the lower horizon, those that remain being of small size only. The trilobites and Cystids form the greater part of the fauna, together with numerous small ostracods, but even a casual scrutiny will reveal the fact that these trilobites are of quite different type for the greater part from those forms in the Caradocian, although when the highest beds of the Caradocian are carefully searched a few of these forms may be found, showing that the new fauna came in gradually. Thus, species of *Cheirurus*, *Lichas*, *Cybele*, *Encrinurus*, *Remopleurides*, and *Staurocephalus* are all highly characteristic of the lowest Ashgillian fauna; and, of these, specimens of *Lichas laxatus*, *Cybele rugosa*, and *Encrinurus sexcostatus* are not infrequently found at the top of the Caradocian. Should conditions in any area have changed more gradually, a greater admixture of the two faunas might be looked for.

Prof. J. E. Marr[1] has divided the Ashgillian into two, the *Phillipsinella* Beds below, and the *Phacops-mucronatus* Beds above, and in a limited sense his classification may be followed in the Bala area. The Rhiwlas Mudstone and Limestone belong unquestionably to the *Phillipsinella* Beds. This *Phillipsinella-parabola* fauna is a very varied and highly characteristic one; a list of the chief fossils found belonging to it is given on p. 172.

The Foel-y-Ddinas Beds which appear to belong to the *Phacops-mucronatus* Beds, on the other hand, have a most meagre fauna, and it is probable that only a small portion of the beds containing that fauna are here represented (see list, p. 156).

There seems to be a complete passage up from these Foel-y-Ddinas Beds, through the Hirnant Beds, to deposits of undoubtedly Silurian age. The Hirnant Beds contain—locally, at any rate—a distinct assemblage of brachiopods that may be regarded as constituting the *Orthis-hirnantensis* fauna (see list, p. 157). This fauna seems to have been included by Prof. Marr in his Ashgillian, as it occurs in the Ashgill Shales.

Significant, also, is the occurrence of *Glyptograptus persculptus* in the higher beds of the Rhiwlas Mudstones (Garth Goch), this graptolite being usually characteristic of the zones of *Dicellograptus anceps* or *Cephalograptus acuminatus*.

[1] Q. J. G. S. vol. lxxi (1915–16) pp. 192 *et seqq.*

Notes on *Strophomena siluriana* Davidson and *Orthis hirnantensis* M'Coy.

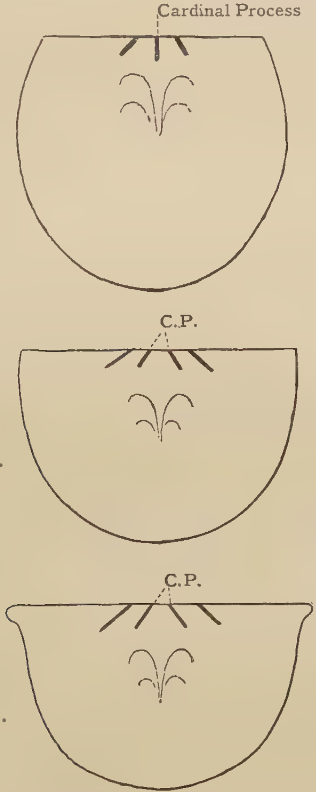
In the Hirnant Beds of the typical locality there occur two brachiopods about which there seems to have been considerable confusion. The following notes are given as a contribution towards clearing up the differences and resemblances which exist between them. The shells are indistinguishable in fragments, for the

Fig. 10.—*Diagrammatic sketches illustrating differences in typical forms of* Orthis hirnantensis *M'Coy and* Strophomena siluriana *Davidson.*

a × 2.

b × 2.

c × 2.



a = Characteristic appearance of brachial valve in *O. hirnantensis.*
b & *c* = Characteristic appearance of brachial valve in two types (alate and non-alate) of *Strophomena siluriana.*

ornamentation of the shell appears to be almost identical in both forms, although with a tendency to a greater coarseness in the form here referred to *Strophomena.*

The relative proportions of the two shells are markedly different:—

In (*a*) the hinge-line is not the greatest width of the shell and the length is approximately the same as the width, which is greatest at the middle of the shell; the angles are obtuse, the pedicle-valve is definitely but gently convex, the brachial valve being nearly flat or very slightly convex, and showing a distinct but single cardinal process.

The structure of the shell is very punctate in between the ribs, and the ribbing characteristically fasciculate. The transverse striations are very clear when the shell is well preserved.

This seems to be the true *Orthis hirnantensis* M'Coy.

In (*b*) the shell is much wider than long, the hinge-line is always the greatest width of the shell, and though at times more pronouncedly 'winged' than at others, the angles of the shell are always acute. The pedicle-valve is very slightly convex in the middle line, the brachial valve flat or slightly concave with a bifid cardinal process.

Shell punctate and ribs fasciculate as in *O. hirnantensis*, but at times rather coarser than in that species.

This appears to be *Strophomena siluriana* Davidson.

VII. Comparison with other Areas.

It is not very easy to compare the shelly faunas of one area with those of another, since there is likely to be less uniformity in the general physical conditions than in the case of those controlling the distribution of the faunas of the deeper parts of the sea, and hence faunas will be likely to show local peculiarities. Correlations of this nature therefore can only be carried out on general lines.

The Derfel Limestone contains a fauna which has not been, up to the present, recorded at that horizon from any other Welsh or English deposits; it does, however, show a noteworthy resemblance to the fauna of corresponding Scottish deposits of that age, as the list given on p. 169 clearly indicates. On the whole, it compares best with that of the Stinchar Limestone, though in some respects, especially as regards the trilobites, it is closer to that of the Balclatchie Beds; it would appear therefore to contain a fauna of the Scottish rather than the Welsh type, which is both interesting and important on palæontological grounds. With regard to the Caradocian rocks of the Bala area, they may perhaps be said to correspond in a general way to beds of similar age in the Glyn-Ceiriog area described by Groom & Lake,[1] but with certain rather striking differences. The Teirw Beds of that area may be paralleled roughly with the Allt-Ddu Mudstones (see lists, pp. 146–47), and to some extent also the Bryn Beds have a fauna resembling that of the Gelli-grin Calcareous Ash; but a noteworthy difference in the fauna seems to be the absence in the Bryn Beds of *Orthis* (*Nicolella*) *actoniæ*, invariably highly characteristic of the beds at Bala (see lists, pp. 147–48). This fossil does, however, appear to be present in the higher shales when they are not faulted

[1] Q. J. G. S. vol. lxiv (1908) p. 546.

off: so, perhaps, if the beds were completely seen, the difference might disappear. This seems all the more likely when the fauna of the Dolhir Beds is studied, because it is here obvious that we are dealing with a mixed fauna which naturally groups itself into two, that characteristic of the Upper Caradocian containing both species of *Chasmops*, *Calymene caractaci*, and abundant *Orthis* (*Nicolella*) *actoniæ* with two large brachiopods; and that generally regarded as belonging to the Ashgillian, which contains *Acidaspis*, species of *Cheirurus* and *Remopleurides*, and small brachiopods. Therefore, the large brachiopods which so frequently disappear concurrently with the appearance of the Ashgillian fauna do not do so in this Glyn-Ceiriog area, remaining and occurring side by side with the smaller characteristic Ashgillian types—*Orthis crispa*, *Strophomena corrugatella*, and *Bilobites biloba*.

Nevertheless, the incoming of new types in abundance, despite the absence of *Phillipsinella parabola*, justifies Groom & Lake in their contention that the beds are of Ashgillian age. The Caradocian beds of Bala perhaps find their nearest analogues in the Shropshire deposits of that age; as the lists given on p. 171 indicate, the fauna of the Soudley Sandstones and lower part of the Cheney-Longville Flags clearly belongs to the *Asaphus-powisi* and *Orthis* (*Heterorthis*)-*alternata* fauna, and unquestionably is closely related to that of the Allt-Ddu Mudstones. Moreover, the Harnage Shales which occur below the Soudley Sandstones contain *Orthograptus truncatus* Lapworth, so that they too afford confirmatory evidence of age as being referable also to the horizon of the zone of *Dicranograptus clingani*. Whether the still lower Hoar-Edge Beds should be paralleled with the Glyn-Gower Beds, or whether these last should be grouped with the Allt-Ddu Mudstones and correlated with the higher beds, there is not sufficient evidence to show.

The upper part of the Cheney-Longville Beds and Acton-Scott Beds, on the other hand, with their abundant *Chasmops* and *Orthis* (*Nicolella*) *actoniæ*, may readily be correlated with the Gelli-grin Calcareous Ash (see list, p. 170).

Turning to the Lake District, I think it is clear that a certain amount of parallelism exists between the beds of certain areas and those of Bala, although the parallelism must not be pressed too closely. The beds that Prof. Marr has described[1] as the *Calymene*-Beds beneath the Ashgillian Series, in the area west of Coniston Lake, are doubtless the faunal equivalents of the Gelli-grin Calcareous Ash, and the occasional specimens of the higher fauna may be noted as parallel with similar occurrences in Wales.

The Ashgillian rocks of the area are also comparable on palæontological grounds with those at Bala; thus the *Phillipsinella*-Beds of Marr contain a fauna which bears a striking general resemblance to that of the Rhiwlas Limestone and Mudstones (see list,

[1] Q. J. G. S. vol. lxxi (1915–16) p. 191.

p. 172). *Phillipsinella parabola* appears to be both generically and specifically a characteristic Ashgillian form, although many other trilobites more characteristic of the fauna have a much longer range in time. Here it may be noted that the general faunal lists of the beds belonging to this horizon are often rather misleading, for they do not bring out the degree of resemblance that undoubtedly exists, since species are apt to be different in widely separated areas and thus the strong generic resemblance is often obscured. The essential distinction between the Caradocian and the Ashgillian faunas as found over the greater part of Wales and the Lake District lies in the genera rather than in the species of trilobites; the species, however, are all-important in discriminating between the Ashgillian fauna proper and the early faunas of Ashgillian type, although indeed some forms are common throughout.

Thus, two widely-separated areas, both containing abundant *Phillipsinella parabola*, and therefore presumably of Ashgillian age, may yield many Cheirurids, Lichads, and Remopleurids, and yet have no species of these genera in common. Consequently, the attempt to show the relationship that probably exists between the faunas of the Rhiwlas Limestone and Mudstones and those of the *Phillipsinella* Beds of the Cautley area, the area west of Coniston Lake, the Keighley Limestone, the Chair-of-Kildare Limestone, and the Sholeshook Limestone in South Wales cannot be regarded as satisfactory (p. 172): there is, in reality, a greater resemblance than these lists indicate.

The Foel-y-Ddinas Beds of Bala represent part, at any rate, of Marr's *Phacops-mucronatus* Beds, although the fauna is very meagrely represented (see p. 156). Marr's Ashgill Shales, on the other hand, contain a fauna which recalls strikingly that of the Hirnant Beds, and, if the two belong really to the same horizon, the question of the upper limit of the Ashgillian Series seems to be involved. The section as seen at Cwm-Hirnant is, in my opinion, strongly suggestive of the Lower Llandovery age of the Hirnant Beds, as otherwise the whole of the Llandovery Series must be comprised within 150 feet of rock—not impossible in an area of deep-water deposition, but hardly likely in a district where shallow-water deposits occur so abundantly in such close proximity.

The sections at Conway [1] would confirm this view.

In conclusion, I would offer my grateful thanks to the many members (past and present) of the Cambridge University Sedgwick Club, who have helped me during the progress of this work, more particularly my pupils Miss H. Drew, Miss A. B. Dale, Miss E. W. Gardner, Mrs. J. Romanes, and Miss M. E. J. Chandler, and Mr. W. B. R. King and Mr. T. C. Nicholas.

To Prof. Marr I am much indebted for consultation in matters relating to the Ashgillian as a whole, and for permitting me to refer to his collections from the Lake District.

[1] G. L. Elles, Q. J. G. S. vol. lxv (1909) p. 169.

VIII. Faunal Lists.

Derfel Limestone. c=common ; r=rare.	Scotland. Stinchar Limestone.	Scotland. Balclatchie Beds.	Welsh Llandilian.	Higher horizons in Wales.
Lichas laxatus M'Coy. c	...	+	...	+
Cybele verrucosa (Dalman). c	+	...	...	+
Cybele rugosa (Portlock). c	...			
Illænus balclatchiensis Reed. c	...	+		
Acidaspis hysterix Wyville Thomson. r	...	+		
Harpes flanagani Portlock. r	+	+		
Trinucleus sp. c	...	+		
Orthis (Platystrophia) biforata (Schlotheim). c	+	+	+	+
Orthis (Nicolella) actoniæ (Sowerby). c	+	...	...	+
Orthis (Nicolella ?) alata (Sowerby). r	...			
Orthis (Hebertella) crispa (M'Coy). r	...	...	...	+
Orthis (Dalmanella) testudinaria var. *gracilis* Reed. r	+	+		
Orthis (Dalmanella) girvanensis (Davidson). r	+	+		
Orthis playfairi Reed. c	+	+		
Orthis (Heterorthis) confinis Salter ? c	+			
Skenidium lewisi var. *craigense* Reed. r	+			
Triplecia craigensis Reed. r	+			
Cliftonia andersoni Reed. c	+	+		
Clitambonites cf. *ascendens* Pander. r	...	...	...	+
Leptæna rhomboidalis Wilckens. c	+	+	...	+
Rafinesquina expansa var. c	+			
Rafinesquina subarachnoidea Reed. c	...	+		
Stropheodonta corrugatella (Davidson). r	...	...	+	+
Plectambonites llandeiloensis (Davidson). c	...	+	+	
Plectambonites sericea var. *semirugata* Reed. c	...	+		
Numerous Bryozoa, and a few Crinoid-stems and Cystid-plates.				

Chasmops & *Nicolella-actoniæ* Fauna. Gelli-Grin Calcareous Ashes. C=very common; c=common; r=rare.	Gelli-grin Ashes, Bala.	Bryn Beds, Glyn Ceiriog.	Up. Cheney Long-ville & Acton Scott Beds, Shropshire.	*Calymene* Beds, Coniston.
Orthis (Nicolella) actoniæ (Sowerby)	C	?	+	+
Orthis (Platystrophia) biforata (Schlotheim)	c	+	+	+
Orthis s.s. *calligramma* Dalman	c	+	+	
Orthis (Hebertella) crispa (M'Coy)	r			
Orthis (Dalmanella) elegantula (Dalman)	C	...	+	+
Orthis (Dinorthis) flabellulum (Sowerby)	c	...	+	
Orthis (Plectorthis) plicata (Sowerby)	C	...	...	+
Orthis (Plæsiomys) porcata (Sowerby)	C	+	...	+
Orthis (Dalmanella) testudinaria (Dalman)	c	+	+	+
Orthis unguis Sowerby	r	...	+	
Orthis (Harknessella) vespertilio (Sowerby)	c	...	+	
Plectambonites quinquecostata (M'Coy)	r			
Plectambonites rhombica (Davidson)	C			
Plectambonites sericea (Sowerby)	C	+	+	+
Plectambonites transversalis (Wahl)	c	...	+	+
Triplecia (Cliftonia) spiriferoides (M'Coy)	C	+		
Leptæna rhomboidalis Wilckens	C	+	+	+
Strophomena (Rafinesquina) expansa (Sowerby)	C	+	+	+
Stropheodonta corrugatella (Davidson)	r			
Lingula ovata Sowerby	r	+		
Calymene caractaci Salter	c	...	+	+
Calymene planimarginata Reed	c	+	+	+
Chasmops conicophthalmus (Bœck)	c	+	?	+
Chasmops macrura (Sjögren)	c	+	+	+
Homalonotus bisulcatus Salter	c	+	+	
Illænus bowmanni Salter	c	...	...	+
Phacops (Acaste) apiculata (Salter)	C	+	+	+
Pterygometopus jukesi (Salter)	C			
Trinucleus concentricus Eaton	C	+	+	+
Trinucleus gibbifrons M'Coy	c			
Beyrichia (Tetradella) complicata (M'Coy)	C	+	+	
Lindstrœmia subduplicata (M'Coy)	r	...	...	+
Halysites catenularia Linnæus	r	...	...	?
Monticulipora lens (M'Coy)	c	+	+	+
Monticulipora lycoperdon (Say)	c	...	+	+
Monticulipora fibrosa (M'Coy)	C	+	+	+
Ptilodictya	r			
Conularia sowerbyi M'Coy	r	...	+	
Glyptocrinus basalis M'Coy	C	..	+	+
Cystid-plates	c	...	...	+
Local assemblages of gasteropods and lamellibranchs. There are also certain 'forerunners' of the Ashgillian beds, of fairly common occurrence in different localities, though as a rule not abundant: such as *Encrinurus sexcostatus, Lichas laxatus, Cybele verrucosa*, and *Agnostus agnostiformis*.				

Asaphus-powisi & Heterorthis-alternata Fauna. Glyn-Gower Sandstones and Allt-Ddu Mudstones. C=very common; c=common; r=rare.	Bala. Glyn-Gower Beds.	Bala. Allt-Ddu Beds.	Teirw Beds, Glyn-Ceiriog.	Shropshire. Hoar-Edge Beds.	Shropshire. Soudley Sandstone.	Shropshire. Lr. Cheney-Longville Beds.
Orthis (Heterorthis) alternata (Sowerby)	r	C	...	...	+	+
var. *retrorsistria* (Davidson)	...	C	+			
Orthis (s.s.) *calligramma* Dalman	r	C				
Orthis (Dalmanella) elegantula (Dalman) var.	c	c	+	+	+	+
Orthis (Dinorthis) flabellulum Sowerby	r	c	...	...	+	+
Orthis (Plectorthis) plicata (Sowerby)	...	C				
Orthis (Plæsiomys) porcata (Sowerby)	...	c	...	...	+	+
Orthis (Dalmanella) testudinaria (Dalman)	r	C	+	+	+	+
Orthis (Harknessella) vespertilio (Sowerby)	c	c	+	+	+	+
Plectambonites sericea (Sowerby)	C	C	+	+	+	+
Plectambonites transversalis (Dalman)	...	r				
Triplecia (Cliftonia) spiriferoides (M'Coy)	...	r	...	...	+	+
Leptæna rhomboidalis Wilckens	...	c				
Strophomena (Rafinesquina) expansa (Sowerby)	r	C	+	+	+	+
Strophomena (Rafinesquina) grandis (Sowerby)	...	r	...	...	+	+
Lingula ovata Sowerby	...	r				
Asaphus powisi Salter	c	C	+	?	+	+
Calymene caractaci Salter	...	r				
Calymene brevicapitata Portlock	r	c	+	+	+	+
Calymene planimarginata Reed	c	c	+	+	+	+
Encrinurus multisegmentatus (Portlock)	r					
Trinucleus concentricus type	c	c	+	+	+	+
Homalonotus bisulcatus (Salter)	?	c	...	+	+	+
Tetradella complicata (M'Coy)	c	C	+	+	+	+
Monticulipora lens (M'Coy)	C	C	+	+	+	+
Monticulipora fibrosa (M'Coy)	...	C	+	+	+	+
Glyptocrinus basalis M'Coy	C	C	...	+	+	+
Ophiurids	...	r				
Bellerophon (Sinuites) bilobatus (Sowerby)	...	r	+	...	+	+
Cyclonema crebristria (M'Coy)	...	r	+	...	+	+
Lophospira gyrogonia (M'Coy)	...	c	+			
Murchisonia cf. *simplex* (M'Coy)	...	r				

Phillipsinella-parabola Fauna. Rhiwlas Limestone and Mudstones. C=very common; c=common; r=rare.	N. Wales.		Lakes.					
	Rhiwlas Limestone and Mudstones.	Dolhir Beds, Glyn Ceiriog.	Coniston.	Cautley.	Keisley.	Chair of Kildare.	Drummuck Beds, S. Scotland.	S. Wales, Sholeshook Lst.
Agnostus agnostiformis (M'Coy)	C	...	+	+	...	+	...	+
Asaphus radiatus Salter	r	...	?					
Ampyx tumidus Salter	r	...	+	+	...	...	...	+
Calymene blumenbachii Brongniart	c	...	...	...	...	...	...	+
Cheirurus bimucronatus (Murchison)	C	...	+ ?	...	+	+	...	+
Cheirurus gelasinosus (Portlock)	c							
Cheirurus juvenis (Salter)	r	+	...	...	...	+	...	+
Cheirurus octolobatus (M'Coy)	c	+	+	+	...	...	+	+
Cybele loveni (Linnarsson)	r	...	...	...	...	...	+	...
Cybele rugosa (Portlock)	c	...	...	+				
Cybele verrucosa (Dalman)	c	+	+	+	...	...	...	+
Dindymene cordai Etheridge & Nicholson	r	...	...	...	...	...	+	...
Encrinurus sexcostatus (Salter)	C	...	+	...	...	...	...	+
Encrinurus multisegmentatus (Portlock)	r	+	...	+				
Illænus bowmanni Salter	C	+	+	+	+	+	...	+
Illænus davisi Salter	C	+	...	...	...	...	...	+
Lichas laxatus M'Coy	C	...	...	+	+	+	...	+
Lichas cf. *bulbiceps* Reed	r	..	...	...	+	+	...	+
Phillipsinella parabola Barrande	C	...	+	+	+	...	+	+
Remopleurides colbii Portlock	c	...	...	?	+	...	+	
Remopleurides radians Barrande	c	...	+	+				
Sphærexochus mirus Beyrich	r	...	...	...	+	+		
Staurocephalus murchisoni Barrande	C	...	+	...	+	+		
Trinucleus seticornis Hisinger	c	+	+	+	...	...	...	+
Trinucleus bucklandi Barrande	c	...	+	+	...	...	+	+
Plumulites peachi (Etheridge & Nicholson)	c	...	+	+	...	...	+	
Caryocystites davisi (M'Coy)	c	+						
Caryocystites granulatus Forbes	c							
Echinosphærites arachnoideus Forbes	C	+	...	+	...	...	...	+
Hemicosmites rugatus Forbes	c	+	...	...	...	...	...	+
Sphæronectes munitus Forbes	r	...	...	...	...	...	...	+
Sphæronectes pyriformis Forbes	c	...	...	...	+			
Sphæronectes punctatus Forbes	r	..	...	...	...	...	...	+
Orthis (Bilobites) biloba (Linnarsson)	r	+	+	...	+			
Orthis s.s. *calligramma* var.	c	+	...	...	+	...	+	+
Orthis (Hebertella) crispa (M'Coy)	C	+	...	+				
Orthis (Dalmanella) elegantula var. *drummuckensis* Reed	c	...	...	...	...	...	+	
Orthis (Dalmanella) elegantula var.	C	+	+	+	+			
Christiania tenuicincta (M'Coy)	C	...	...	+	+	+	...	+
Hyattella portlockiana (Davidson)	C	...	...	?	+	+		
Skenidium lewisi (Davidson)	r	...	...	+	...	...	...	+
Plectambonites quinquecostata (M'Coy)	c	+	...	+	+	...	...	+
Stropheodonta corrugatella (Davidson)	c	+	+	+	+	+	...	+
Orthoceras vagans Salter	c							
Holopea concinna M'Coy	r	+	...	...	+	+		
Many small ostracods and a few larger forms abundant. Also some 'survivors' from the *Chasmops* Fauna, though these are usually very rare: namely, *Chasmops* sp., *Acaste apiculata*, *Platystrophia biforata*, and *Nicolella actoniæ*.								


MAP OF COUNTRY
E. & S.E. OF
BALA LAKE.
INDEX
HIRNANT BEDS.
HIRNANT LIMESTONE.
FOEL-Y-DDINAS MUDSTONE.
MOEL-FRYN SANDSTONES.
RHIWLAS MUDSTONES.
RHIWLAS LIMESTONE.
GELLI-GRIN & BRYN PIG LST.
MOEL-FRYN LST.
GELLI-GRIN
CALCAREOUS ASH.
CAE'R HAFOTTY LST.
PONT-Y-CEUNANT ASH.
ALLT DDU MUDSTONES & LIMESTONES.
FRONDDERW ASH.
RHYD-WEN LST.
GLYN-GOWER SANDSTONES.
NANT-HIR SHALES
DERFEL LST.
BALA
BALA & FFESTINIOG RY.
Afon Tryweryn
River Dee
LLYN TEGID DISPLACEMENT
LLYN TEGID or BALA LAKE
BALA LAKE DISPLACEMENT
G.W.R. BALA & DOLGELLY SECTION
LLANGOWER DISPLACEMENT
CEFN-DDWY-GRAIG DISPLACEMENT
MOEL-FRYN DISPLACEMENT
FFRIDD DEFAID DISPLACEMENT
LLANDOVERY-TARANNON
Llanycil
Llangower
Lake Vyrnwy Rd.
Penygarth
Y Garnedd
Pandy Isaf
Garth Goch
Llandderfel
Plas Rhiwaedog
Rhos-y-gwalian
Ffridd Defaid
Efridd Gelli grin
Ysbyddadog
Bryn-melyn
Gelli-grin
Wenallt
Cornelau
Bryn Porfa
Bryn Bedwog
Bryn Pig
Moel Fryn
Coed y Gilwern
Pant-yr-onen
Glyn Bach
Cae'r-hafotty
Maesmeillion
Foel Caer hafotty
Murddyn Marad
Cwm yr aethnen
Cwm Hirnant
Lake Vyrnwy
Drift
1567·4
N.
Scale. 4 inches = 1 mile,
or 1:15,840.

EXPLANATION OF PLATE II.

Geological map of the country east and south-east of Bala Lake, on the scale of 4 inches to the mile, or 1 : 15,840.

Discussion.

Prof. O. T. Jones congratulated the Author on the completion of an extremely interesting research upon a complicated district, one which, as was known from his writings, drove so accomplished a geologist as Jukes almost to despair.

The paper raised many interesting questions, both of the nomenclature and structure, and particularly furnished information as to the relation of the Llandeilo and Bala formations. The discovery of the *Nemagraptus-gracilis* fauna in the Derfel Limestone, associated with brachiopods similar to those in the Stinchar Limestone, was extremely interesting.

In Sedgwick's final classification the base of the Bala was drawn at the base of the strata overlying the 'porphyries' of Arenig. The relation of these 'porphyries' to the Llandeilo formation of South Wales was unknown. In South Wales it has been shown that the *Nemagraptus* fauna overlies directly everything that can be assigned by definition to the Llandeilo formation, and it was satisfactory, therefore, to find from the Author's new evidence that the line proposed by Sedgwick for the base of the Bala in North Wales coincided with the line that was adopted by the Geological Survey in South Wales by direct reference to the Llandeilo formation. It further became clear that the terms 'Llandeilo' and 'Bala' bore very little relation to Llandeilian and Caradocian.

See G. M. corresp. re. O.T. Jones v. Elles.

He did not quite understand the Author's caution about regarding a fauna of Ashgillian type in South Wales and elsewhere as necessarily indicating Ashgillian age. The Rhiwlas Limestone of North Wales, with its *Phillipsinella-parabola* fauna, coincided precisely with the beds which were taken to mark the base of the Ashgillian in South Wales; and the numerous brachiopods from rocks of Ashgillian age, which the speaker had examined from various localities in North Wales, agreed closely with those of the corresponding rocks in South Wales.

The position of the Hirnant Limestone apparently still remained unsatisfactory. The striped shales which succeeded it appeared to correlate with the Birkhill Shales farther south, where, however, they were thicker than at Hirnant, and it was also rather surprising that they yielded no graptolites, considering their extremely fossiliferous character farther south.

He enquired whether there was a possibility that some part of the sequence was cut out by strike-faulting, in view of the existence of several faults of this type ranging towards the area from the south. He also asked whether there was any direct evidence of great lateral movements along the line of the Bala Fault itself, as seemed to be the case in the neighbourhood of Talyllyn, on what was apparently the continuation of the same fault.

Dr. A. Wade said that perhaps some observations made by himself might help a little towards the solution of the problem of the Hirnant Limestone in the area dealt with in this valuable paper. On the eastern side of the Welshpool area the base of the Llandovery was, as a rule, a massive conglomerate, sometimes calcareous and containing *Pentamerus*. On the north-western flank the conglomerate was still present, but tended to pass into finer sandstones, and in places thinned out altogether. It was, however, represented by large blocks of limestone, lenticular and non-continuous, which seemed to contain great quantities of *Orthis* and similar brachiopods, and practically no *Pentamerus*. The Llandovery here lay unconformably on the Upper Ordovician rocks, so that the position of the beds was fairly easily determined. Such changes apparently took place in these rocks in the area now described, and possibly such a change accounted for the difficulties in connexion with the Hirnant Limestone.

Mr. A. K. Wells stated that, as one of the younger workers in North Wales, he wished to add his congratulations and thanks to the Author for her very lucid account of the geology of what was well known to be one of the most difficult areas in that region. He was particularly interested in the discovery of a fossiliferous band in the series of monotonous mudstones that succeed the highest volcanic rocks in the Arenig district—a discovery that would go far towards proving the relative age of these lavas. The fauna seemed to be very similar to that found immediately above the volcanic rocks at Llanwrtyd Wells by the speaker's colleague, Mr. L. D. Stamp. Here, however, the same graptolites were discovered in another shale-band within the volcanic rocks. The speaker, working in the Rhobell-Fawr district, a few miles west of Bala, had found similar shales containing graptolites, which, though poorly preserved, would probably prove to be from the same horizon.

Mr. C. B. Wedd wished to associate himself with earlier speakers in congratulating the Author on her completion and lucid presentation of a most valuable piece of work. He felt that the structural details were too complex to discuss offhand, and asked whether the Author could give further information as to the effect of the movements upon direction and hade of cleavage.

Dr. C. A. Matley also congratulated the Author, and enquired whether she had found in the Bala area, at or near the horizon of the Derfel Limestone, any representative of the oolitic ironstone which occurred in the Glenkiln Beds of Anglesey and Carnarvonshire.

Prof. W. W. Watts congratulated the Author on her courage in tackling so difficult a district. He referred to the interesting point brought out in the paper that the Derfel Limestone yielded the 'exotic' fauna, which the Author had particularized in the Stinchar Limestone and elsewhere. He hoped that the time was coming when it would be possible to use only palæontological

time-horizons, and that the innumerable, and often cacophonous, local horizon-names would be dropped.

The AUTHOR, in reply, thanked the Fellows for their generous reception of her paper. In answer to Prof. Jones, she stated that, with regard to the boundary between the Llandeilian and the Caradocian, she based her position on the palæontological aspect of the question. She regarded the rocks of the 'shelly' facies of the Welsh Ordovician as belonging to different faunas—the *Ogygia-selwyni* fauna, the *Placoparia* fauna, the *Ogygia-buchi* fauna, the *Calymene-planimarginata* fauna, the *Phillipsinella-parabola* fauna, and the *Phacops-mucronatus* fauna; and, so long as beds contained the same *Ogygia-buchi* fauna as those of the Llandeilo area, she considered them Llandeilian in age. The beds with the *Nemagraptus-gracilis* fauna, and even slightly higher graptolitic horizons, were associated with the *Ogygia-buchi* fauna in the Builth area, and were, therefore, in her opinion, of Llandeilian age.

With regard to the calcareous development of the Gelli-grin Calcareous Ashes and the Rhiwlas Beds being usually separate as in South Wales, that was not the case invariably in the Bala country, since both occurred superposed at Bryn-pig.

She had looked for evidence of faulting at Cwm Hirnant, but could find none; the beds were steeply inclined, yet along the old adits there seemed to be a perfectly continuous section from the Hirnant Beds to the shales with *Monograptus crispus*.

There certainly was evidence in the area north-west of Bala Lake of movements similar to those on the south-eastern side; these appear to be related to a major thrust running at or near the junction of the *Dicranograptus* Shales with the volcanic rocks. She regarded the entire country as being thrust above the volcanic series as a whole.

In answer to Mr. Weld, she stated that, while the cleavage in the southern part of the area was inclined steeply east-south-eastwards, when the effects of the east-and-west movement made themselves felt in the northern part of the district, a second cleavage seemed to be developed, the exact direction of which she had not determined.

She was in complete agreement with Prof. Watts in regard to the growth of all these local names, which, however, were certainly useful for local reference, but suggested the adoption of the palæontological classification of wide application for all other purposes.

4. *The* Lower Palæozoic Rocks *of the* Llangollen District, *with special reference to the* Tectonics.

By Leonard Johnston Wills, M.A., Ph.D., F.G.S., and Bernard Smith, M.A., F.G.S. (Read January 19th, 1921.)

[Plates III–V—Geological Maps & Sections.]

Contents.

I. Introduction.

The area dealt with in the following pages forms the western half of the 1-inch Ordnance Survey Map, New Series, Sheet 121, with small contiguous strips in Sheets 120 & 137. It was mapped by us in the course of official work for the Geological Survey, in 1912 & 1913. The memoir on Sheet 121 is in preparation; but both it and the map which it accompanies have been greatly delayed by the War. This applies even more emphatically to Sheet 137. In the projected memoir on Sheet 121, special attention will be devoted to the Wrexham-Ruabon Coalfield.

In preparing the present paper, we have been influenced by a desire to publish in a concise form[1] an account of the older rocks which are more of theoretical than economic importance. We have attempted to describe the district as a geological unit, whereas the Survey Memoir must be primarily an explanation of the map and of the evidence on which it is based.

We are, therefore, greatly indebted to the Director of H.M. Geological Survey for permission to publish the following account, which is divisible into two parts. In the first, we aim at stating new facts and important modifications of the hitherto accepted ideas of the stratigraphical sequence, without traversing in detail the work of previous investigators where their conclusions have been confirmed by us. In the second part, we give a fuller description of the tectonics than the space available in the official Memoir would allow.

Our sincere thanks are due to Mr. C. B. Wedd and Mr. W. B. R. King for help and friendly criticism, and to Miss G. L. Elles,

[1] The arbitrary limits of the map-sheets are not those of a natural geological region. Accordingly, important parts of the sequence, because they happen to lie in one sheet, have to be omitted in the official description of the other.

Prof. O. T. Jones, Mr. Philip Lake, and Mr. John Pringle for the determination of fossils—a difficult task with material so distorted by cleavage. To Dr. H. H. Thomas we are greatly indebted for his examination of some of the more difficult rock-types.

II. Historical Summary.

Pending the publication of the new Geological Survey map, upon which the map (Pl. V) is based, the reader is referred to the Old Series map, Sheets 74 N.E., N.W., & S.E., in which the major features of the structure are well displayed. This, it is believed, was largely the work of T. W. Aveline and J. B. Jukes.

More recent research has been confined, with few exceptions, to the southern part of the area, that is, between the Dee Valley and the Berwyns.

Our present knowledge of the succession is largely due to the work of Dr. T. T. Groom & Mr. P. Lake,[1] whose paper on Glyn Ceiriog contains a full bibliography.

The zonal classification of the Salopian was described, in the case of the Wenlock by Miss G. L. Elles,[2] and in the case of the Lower Ludlow Series by Dame Ethel Shakespear (*née* Wood).[3]

The igneous rocks of the Berwyns have been redescribed in a posthumous paper by T. H. Cope.[4]

North of the Dee the geology of the Lower Palæozoic rocks has been barely touched, although reference may be made to early work by the late Prof. T. McK. Hughes[5] and to the maps made by Sir Aubrey Strahan[6]; also to his description of the area lying north of Llandegla. The work of G. H. Morton was confined to the Carboniferous rocks.

During the recent survey, brief notices were published in the 'Summary of Progress' of the Geological Survey for the years 1911, 1912, & 1913. One of us has also given a sketch of the geology of the Llangollen district.[7]

[1] T. T. Groom & P. Lake, 'The Llandovery & Associated Rocks of the Neighbourhood of Corwen' Q. J. G. S. vol. xlix (1893) pp. 426–39; T. T. Groom & P. Lake, 'The Bala & Llandovery Rocks of Glyn Ceiriog' *ibid.* vol. lxiv (1908) pp. 546–95; and P. Lake, 'The Denbighshire Series of South Denbighshire' *ibid.* vol. li (1895) pp. 9–22.

[2] 'The Zonal Classification of the Wenlock Shales of the Welsh Borderland' Q. J. G. S. vol. lvi (1900) pp. 370–413.

[3] 'The Lower Ludlow Formation & its Graptolite-Fauna' *ibid.* pp. 415–91.

[4] 'On the Igneous & Pyroclastic Rocks of the Berwyn Hills' Cope Memorial Vol. Proc. Liverpool Geol. Soc. 1915.

[5] Q. J. G. S. vol. xxxiii (1877) p. 207.

[6] 'The Geology of the Neighbourhoods of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, pp. 4–6.

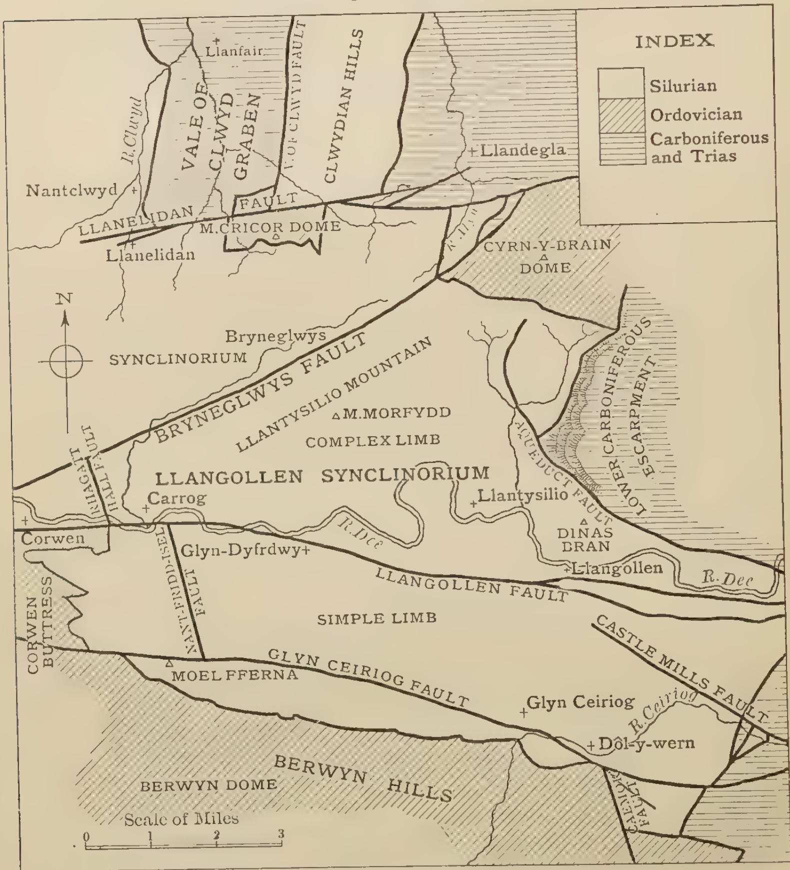
[7] L. J. Wills, 'The Geology of the Llangollen District' Proc. Geol. Assoc. vol. xxxi (1920) pp. 1–15.

III. Stratigraphy.

(A) General Considerations.

The southern part of Denbighshire and the adjoining portion of Merionethshire, described in this communication, form a rather flat-topped upland, deeply dissected in the south-east by the Dee,

Fig. 1.—*Outline-map showing the chief tectonic features of the Llangollen district.*



the Ceiriog, and their tributaries. A depression runs north-eastwards from Corwen across the upland, along the line of the Bryneglwys Fault.[1] The drainage from this flows in part to the Dee and in part to the Alyn. In the northern part of the area

[1] Sometimes known as part of the Bala Fault, see p. 219.

the Vale of Clwyd forms a great sunken graben nosing southwards into the upland.

The chief structural units of the district are shown in the outline-map (fig. 1), and the general arrangement of the formations in the map forming Pl. V.

(B) Ordovician.—The Bala Formation.

In the three anticlinal areas: namely, the Berwyns, Cyrn-y-Brain, and Mynydd-Cricor, rocks referable to the Ashgillian Series of the Bala Formation are found, while in the Berwyns the underlying Caradocian Series also comes to the surface.

The sequence of the complete Bala Formation in the Glyn-Ceiriog district at the eastern end, and in the Moel-Fferna district at the western end, of the Berwyn outcrop is set out in Table I, pp. 180–81. The Ashgillian development of the Bala in the two northern anticlines is also shown.

Where it has been found practicable, the names instituted by Dr. Groom & Mr. Lake (*op. cit.* 1908) have been adopted; but it was found, on mapping still farther west, that their 'Graptolitic Slates' embraced two different formations of importance, to which the names 'Blaen-y-cwm Beds' and 'Ty'n-y-twmpath Beds' have been assigned.

Caradocian Series.

(1 & 2) Teirw Beds and Cwm-Clwyd Ash.—In considering the Caradocian Series in the Northern Berwyns, it is unnecessary to redescribe the Teirw Beds in the Glyn area, so fully are they dealt with by Dr. Groom & Mr. Lake; but farther west appears a thick ash-band which, on the Old Series map, was correlated with the Pandy Ash. It lies, however, in the middle of the Teirw Beds and may be called the Swch-Gorge Ash, since it is best exposed in the gorge of the Ceiriog near Swch-cae-rhiw.

The following is the sequence here:—

Bryn Beds.	Pen-y-graig Ash.
	Fossiliferous mudstones.
	Pandy Ash, seen at the top of the gorge.
Teirw Beds.	Mudstones and sandstones, with two thin ashes or agglomerates.
	Swch-Gorge Ash in two bands, the lower containing rolled pebbles of hard shale.
	Sandstones and sandy shales, with a thin ash-band.
	Cwm-clwyd Ash in two bands.

The age of the Teirw Beds is in doubt, because they appear to contain a fauna intermediate between Llandeilian and Caradocian, a fact hinted at by Dr. Groom & Mr. Lake (*op. cit.* 1908, pp. 589–90). To the forms enumerated by them (*ibid.* p. 559) we can

TABLE I.

The Bala Formation.

		Glyn-Ceiriog District.	Moel-Fferna District.	Cyrn-y-Brain and Mynydd-Cricor.
Ashgillian.	8.	Glyn Grit.	Corwen Grit.	Plas-uchaf Grit.
		(*b*) Massive, fine-grained, uncleaved grit.	Massive, fine-grained, uncleaved grit.	Massive ashy grit, and on Cricor platy grits and shales.
		(*a*) Thinly-bedded fossiliferous grit or sandstone, locally interbedded with platy limestones.		
	7.	Dolhir Beds.	Dolhir Beds.	Cyrn-y-Brain Beds.[1]
		(*b*) Very fossiliferous, cleaved, micaceous shales, with some calcareous bands.	(*b*) Cleaved shales, usually less fossiliferous and more sandy than at Glyn.	(*b*) Tough, ashy, cleaved greywacke shales and sandstones, and one thin fossiliferous ash-band, on soft, micaceous, very fossiliferous sandstone.
		Chasmops macroura, *Harpes dorani*, *Sphærocoryphe thomsoni*, *Phacops brongniarti*, *Trinucleus seticornis*.	As near Glyn, but with *Meristina crassa* near the top.	*Calymene senaria*, *Phacops brongniarti*, *Chasmops macroura*, *Meristina crassa*, *Orthis hirnantensis*, *Clitambonites ascendens*.
	7.	Dolhir Limestone.	Ty'n-y-twmpath Beds.	
		(*a*) Limestone containing corals, interbedded with shales.	(*a*) Compact, grey, cleaved shale, sometimes speckled. Few fossils, except locally.	
			Agnostus agnostiformis, *Trinucleus seticornis*, *Phillipsinella parabola*, *Phacops truncato-caudatus*.	
	6.		Blaen-y-cwm Beds.	
		Absent, ? by faulting.	Dark-blue or black graptolitic mudstones, poorly cleaved. ? Zone of *Diplograptus pristis*.	

[1] Not to be confused with the Gwern-y-brain Group in the Welshpool district, described by Dr. A. Wade, Q. J. G. S. vol. lxvii (1911) p. 422.

TABLE I (*cont.*).

CARADOCIAN.	5.	Pen-y-graig Ash.	Pen-y-graig Ash?
		Thin keratophyric ash, only found at intervals.	Not observed west of Tomen-y-bwlch.
	4.	Bryn Beds.	
		Dark-blue slates and argillaceous, siliceous, and ashy sandstones, thin ashes and conglomerates. Sills of lime-bostonite in places. *Homalonotus bisulcatus*, *Trinucleus concentricus*, *Orthis elegantula* (large), *Phacops apiculatus*.	Dark-blue slates.
	3.	Pandy Ash.	Pandy Ash.
		Agglomeratic, coarse and fine-grained keratophyric tuff, with occasional blocks of keratophyre. Very variable in thickness.	
	2.	Teirw Beds.	Teirw Beds.
		(*b*) Rather unfossiliferous slates and thin, often uncleaved sandstones, with some thin bands of ash.	Practically unfossiliferous shales and sandstones, with a thick double band of ash incorporating pebbles of shale, in the middle of the series (Swch - Gorge Ash).
		(*a*) Massive sandstones with *Glyptograptus teretiusculus* and *Calymene (?) planimarginata*, *Asaphus powisi*, *Trinucleus concentricus*.	
	1.	Cwm-clwyd Ash.	Cwm-clwyd Ash.
		Massive and well-bedded, almost platy keratophyric ash, coarse or fine in grain.	

add *Calymene planimarginata (?)* Reed, *Orthis (Platystrophia) biforata* Schlotheim, *Orthis (Dalmanella)* cf. *testudinaria* Dalman, *Cryptograptus* cf. *schäferi* Lapworth, and *Diplograptus (Glyptograptus) teretiusculus* (Hisinger).

The graptolites were found by Mr. W. B. R. King in the lower part of the series near Pandy, and in Miss Elles's opinion suggest a Llandeilian age—possibly even the zone of *Diplograptus teretiusculus*. On the other hand, the *Plectambonites sericea* from slightly higher beds is pronounced by Prof. O. T. Jones to be similar to the Soudley-Sandstone form of this species.

Until further evidence of the exact age is forthcoming, the Cwm-clwyd Ash at the bottom of the Teirw Beds, in that it occurs on the south as well as on the north of the Berwyn Anticline, forms the most convenient base to the Bala Series in this district.

(3) The Pandy Ash.—The Pandy Ash, although variable in thickness, forms a useful horizon for mapping. It contains fragments of keratophyre in its coarser parts, and forms the highest ash at the Falls of the Ceiriog, where it was formerly regarded as the 'Little Ash' of Jukes (that is, perhaps, the Pen-y-graig Ash).

(4 & 5) Bryn Beds and Pen-y-graig Ash.—As pointed out by Dr. Groom & Mr. Lake, the Bryn Beds vary considerably in thickness and composition from east to west. From place to place, the rocks are penetrated by sills of lime-bostonite, the best-known example being the Coed-y-glyn Sill near Glyn-Ceiriog. The base of the Bryn Beds overlies the Pandy Ash. On the west of the Glyn valley, at least as far west as Tomen-y-bwlch ($1\frac{1}{4}$ miles west-south-west of Nantyr), and possibly farther, under the cover of peat, their summit is at several places proved to be defined by the 'Pen-y-graig Ash' of Groom & Lake. This is a thin, usually sheared, keratophyric ash, which is, perhaps, impersistent between the known limits of its outcrops. Throughout the western region, the Bryn Beds are rather uniformly dark-blue sandy mudstones or sandstones, often yielding abundant fossils.

East of the Glyn Valley the upper part of the group is, in the main, similar in lithology, but is underlain by a series of shales containing numerous bands of felspathic sandstone, which increases the total thickness of the Bryn Beds very considerably (see Table II, p. 189, & fig. 3, p. 185). The Pen-y-graig Ash is, in our opinion, absent in this region. In adopting this view we differ from Dr. Groom & Mr. Lake, for they regarded an ash which occurs above a massive sandstone at Bryn (in Nant-Iorwerth, south-east of Glyn-Ceiriog) as the Pen-y-graig Ash. The ash at Bryn, however, does not form the top of the Bryn Beds here, nor does it closely resemble the Pen-y-graig Ash. In our opinion, the following sequence can be established for the Bryn Beds near Bryn (see fig. 2, p. 184). It is of interest, as providing evidence of local contemporaneous movements.

Sequence in the Bryn Beds near Bryn.

	Thickness in feet.
6. Blue sandy mudstones with fossils	about 70
5. Subangular conglomerate, or breccia, in parts becoming a felspathic ash	$2\frac{1}{2}$
4. Blue sandy mudstones containing *Orthis elegantula*	$2\frac{1}{2}$ to 3
3. Coarse felspathic ash, calcareous in part, passing in its centre into an agglomerate of compact shale-fragments. The top of the ash contains *O. elegantula*, and the bottom locally is an extremely fine-grained tuff........................	$2\frac{1}{2}$
2. Massive felspathic sandstones with abundant fossils locally, and some thin bands of shale. (Bryn Sandstone.)	30
F. Fault, downthrow to the north-east.	
1. Cleaved shales, with thin bands of felspathic sandstone ...	350 to 400
Pandy Ash.	

The conglomerate (5) has not been observed *in situ* elsewhere; but blocks of a rock similar to the agglomerate in 3, built into a wall on the roadside, 200 yards south of Pant (half a mile west of Bryn), were probably quarried near there.

The lower conglomerate contains pebbles of keratophyric ash, similar to the Pandy Ash, and also pebbles of a curious micaceous and very siliceous rock, which forms part of the Bryn Beds themselves. It crops out about 470 yards south-east of Pant and also at Ty-nant (on the Oswestry road, half a mile south-east of Bryn). It was here mistaken for an outcrop of the Coed-y-glyn Sill by Groom & Lake; microscopic examination, however, shows it to be a clastic rock, very fine-grained in part, but clearly resembling an ash in its coarser portions.

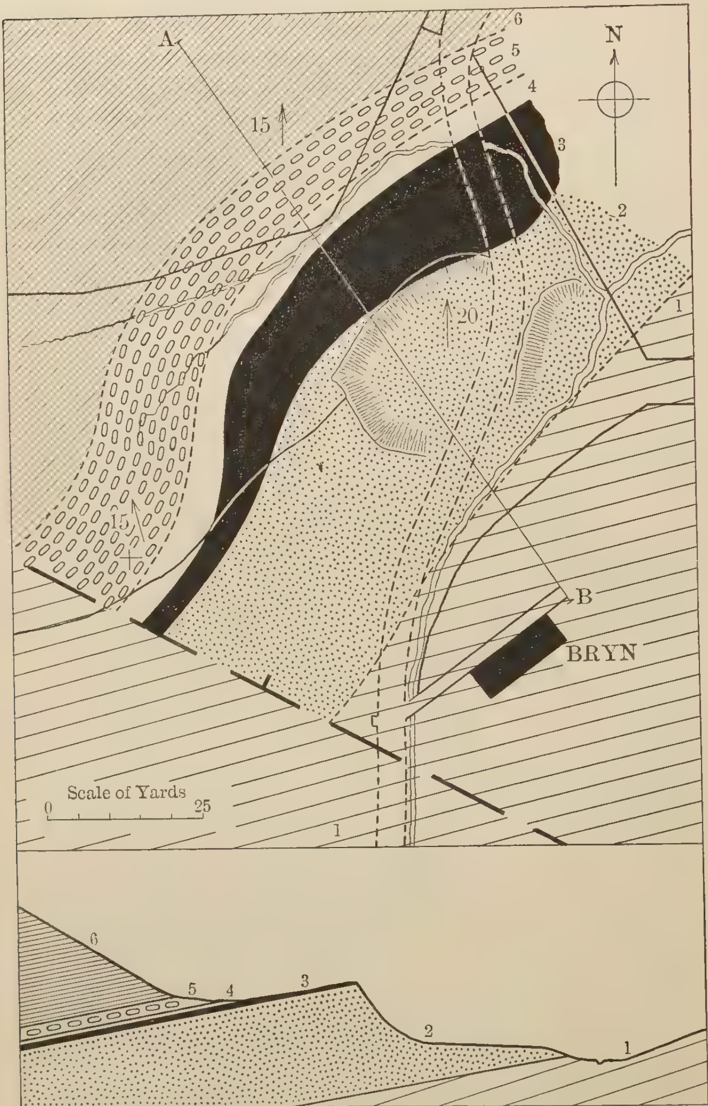
The presence of these pebbles in the conglomerate at Bryn seems to prove that the rocks near here were sufficiently uplifted during the formation of the Bryn Beds for erosion to reach even the Pandy Ash at the base of the group. Thus it appears that the upward tendency of the Berwyn Dome was in evidence even at that early date.

(6) Blaen-y-cwm Beds.—These are black graptolitic mudstones, in which the fossils are poorly preserved. They take their name from a farm near Nantyr, where they are well exposed.

From their easternmost exposure near Gelli ($1\frac{1}{2}$ miles south-west of Glyn-Ceiriog) they can be traced as far west as the mapping has been undertaken. In this region they overlie the Pen-y-graig Ash wherever it has been proved. The beds disappear east of Gelli, the Dolhir Beds resting directly upon the Bryn Beds (fig. 3, p. 185).

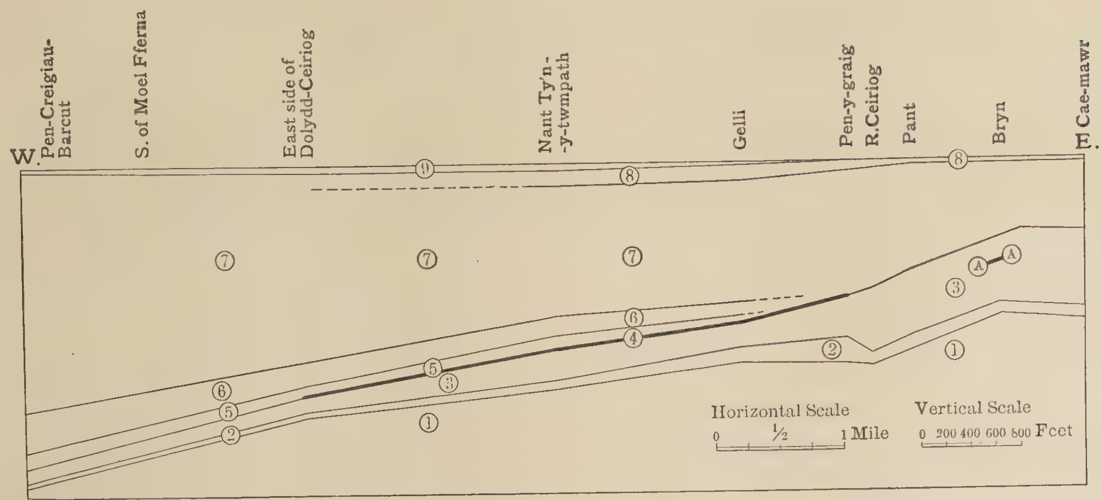
The zonal position of the Blaen-y-cwm Mudstones is still a matter of doubt, on account of the unreliable evidence afforded by the badly-distorted graptolites. Miss G. L. Elles, to whom the fossils were submitted, thought that the following forms were represented:—*Dicellograptus* sp., *Dicranograptus tardiusculus* Elles & Wood, *Diplograptus* (*Orthograptus*) *calcaratus* Lapworth var. *acutus* Elles & Wood, *D.* (*O.*) *calcaratus*, var. *vulgatus*

Fig. 2.—*Plan and section (A–B) of the Bryn locality.*



6 = Sandy fossiliferous shales (Bryn type).
5 = Angular conglomerate.
4 = Sandy fossiliferous shale.
3 = Ash passing locally into agglomerate.
2 = Bryn Sandstone, massive and fossiliferous.
1 = Beds below the Bryn sandstone, consisting of shales and thin ashy sandstones.

Fig. 3.—*Variation in thickness in the Bala Formation, Northern Berwyns.*



9 = Massive Glyn-Corwen Grit.
8 = Fine-grained Glyn Grit and Limestone.
7 = Dolhir Beds.
6 = Ty'n-y-Twmpath Beds.
5 = Blaen-y-cwm Beds.
4 = Pen-y-graig Ash.
3 = Bryn Beds, with A, the ash at Bryn.
2 = Pandy Ash.
1 = Teirw Beds.

Elles & Wood, *D.* (*Mesograptus*) *multidens* Elles & Wood, *D.* (*Amplexograptus*) *perexcavatus* (?) Lapworth, *D.* (*Glyptograptus*) *teretiusculus* (Hisinger), *D.* (*G.*) *teretiusculus* var. *euglyphus* Lapworth.

Dr. Groom & Mr. Lake further record *Dicellograptus elegans* Carruthers. This latter form suggests a horizon about the zone of *Pleurograptus linearis*, which would agree with the position of the rocks above the Bryn Beds that show a typical Caradocian fauna. The other identifications suggest a much lower horizon, possibly even in the Llandeilo, which goes counter to all the stratigraphical relations that can be shown in the case of the Blaen-y-cwm Beds. In view of this discrepancy, it is interesting to note that, at Pen-y-garnedd on the south side of the Berwyns, one of us, together with Mr. W. B. R. King, found well-preserved graptolites in black shales, occupying the same stratigraphical position.[1] The fossil assemblage occurring there has been claimed by Miss Elles as proving the presence of the *Diplograptus-pristis* Zone of Sweden, hitherto unrecognized in this country. That zone is approximately equivalent to the zone of *Pleurograptus linearis*. Therefore, until really well-preserved forms are forthcoming from the Blaen-y-cwm Beds, we are inclined to attach more importance to the evidence, stratigraphical and palæontological, which points to the *Pleurograptus-linearis* Zone, than to identifications, based on admittedly inadequate material, suggestive of a far lower horizon.

Ashgillian Series south of the Llangollen Synclinorium.

(7) Dolhir Beds.—The general lithological characters of the Dolhir Beds have already been indicated in Table I, p. 180, and the variation in thickness is shown in Table II, p. 189, and fig. 3, p. 185.

(*a*) Lower or Ty'n-y-twmpath Beds.[2]—A group of grey slates, often with difficulty separable from the normal micaceous Dolhir Slates, comes in above the Blaen-y-cwm Beds, near Gelli, and thickens westwards, where it is frequently characterized by a speckly blotching of the rocks. It is usually far less fossiliferous than the Dolhir Beds proper, although locally it contains a rich fauna of trilobites.

The upper and lower limits of this group merge into the Dolhir and Blaen-y-cwm Beds respectively, by insensible gradations, and it has not been possible to draw satisfactory boundaries to the formation on the map. It is also uncertain whether the Ty'n-y-twmpath Beds are the equivalent in the west of the Dolhir Limestone, which, with its associated shales, forms the base of the Dolhir Beds near Glyn-Ceiriog.

[1] 'Summary of Progress for 1919' Geol. Surv. 1920, pp. 4, 5.

[2] This group takes its name from a large farm, lying immediately west of the small homestead indicated as Bonc, about three-quarters of a mile east of Nantyr. Nant-Ty'n-twmpath, referred to in the sequel, is the valley that descends from the north to the farm.

The distinctive Ashgillian fauna of this lowest member of the Dolhir Beds is set forth below :—

c=common.	1.	2.	3.	4.	5.
Favosites fibrosus Goldfuss	x	x	..	x	
Cf. *Monticulipora lens* M'Coy	...	...	...	x	
Orbiculoidea perrugata M'Coy	...	...	...	x	
Leptæna rhomboidalis Wilckens	x	...	...	x	
Orthis flabellulum J. de C. Sowerby	...	...	c		
Orthis calligramma Dalman	...	x	x	x	
Orthis calligramma, var. *plicata* J. de C. Sowerby	...	...	c	x	
Orthis (*Dalmanella*) *elegantula* Dalman	...	...	x		
Orthis (*Dalmanella*) *testudinaria* Dalman	...	x			
Orthis (*Hebertella*) *vespertilio* J. de C. Sowerby	...	...	...	...	x
Plectambonites scissa Salter	...	...	...	x	x
Plectambonites sp.	...	..	x		
? *Triplecia insularis* Eichwald	...	x			
Agnostus agnostiformis McCoy	...	x	...	...	x
Agnostus cf. *agnostiformis*	...	...	...	x	
Calymene senaria Conrad (Salter)	...	x	x	...	x
Calymene cf. *caractaci* Salter	...	...	...	...	x
Chasmops sp.	...	...	...	...	x
Cybele cf. *verrucosa* Dalman	...	...	...	...	x
Encrinurus sp.	...	...	...	x	x
Illænus sp.	...	...	x		
Lichas sp.	...	...	c		
Phacops truncato-caudatus Portlock	...	...	...	...	x
Phillipsinella parabola Barrande	...	...	...	...	c
Sphærocoryphe thomsoni (?) Reed	...	...	c		
Trinucleus cf. *nicholsoni* Reed	...	...	...	...	x
Trinucleus seticornis Hisinger	x	...	...	...	x
Trinucleus sp.	...	...	x	...	x

(1) Ty'n-y-celyn Farm, near Nantyr.
(2) Ty'n-y-twmpath stream, 150 yards north of the farm.
(3) Lane at Bonc.
(4) Old quarry, by the entrance-lodge to Plas Nantyr.
(5) Headwaters of Nant-y-Lladron, 3 miles south by east of Corwen.

(*b*) Upper or Dolhir (*sensu stricto*) Beds.—The remainder of the Dolhir Beds includes the rocks so designated by Dr. Groom & Mr. Lake near Glyn, and needs no further description so far as the eastern part of their outcrop is concerned. Westwards, however, the group, as mapped by us, thickens (fig. 3, p. 185), and becomes more sandy, especially in its upper part, which embraces shaly sandstones that are almost certainly the equivalent of the lower part of the Glyn Grit of Glyn-Ceiriog. These beds are not separable in the field from the main part of the group, but their arenaceous nature provides a type of lithology intermediate between the Dolhir Slates of Glyn and the greywacke slates and sandstones of the Cyrn-y-Brain Beds. It is accordingly interesting to find *Meristina crassa* occurring in them as a rarity, for this fossil may be said to be one of the most abundant and characteristic forms in the Cyrn-y-Brain Beds.

The Ashgillian age of the Dolhir Beds was established by

Groom & Lake. In addition to the forms recorded by them, we may note *Harpes dorani*[1] Portlock and *Sphærocoryphe thomsoni (?)* Reed.

(8) Glyn-Corwen Grit.—The Glyn Grit at Glyn is a platy sandstone passing down into a limestone, the two rocks being interbedded at their junction. The peculiarities and fauna of these rocks were described by Groom & Lake at some length. When traced westwards an upper massive grit is found to come in about a mile west of Glyn, and it is this upper grit which has been proved by us to be the continuation of the Corwen Grit. The disappearance of the platy grit westwards has just been noted. It is interesting, however, to find near the Ty'n-y-twmpath stream that the upper massive grit is succeeded upwards by thin beds of grit interbedded with the Lower Valentian Slates, in the same manner that farther east the platy grit passes upwards into the slates, as described by Groom & Lake.[2] Near Corwen shaly bands in the grit resemble lithologically the Dolhir Beds.

Thus it appears that we must treat the Corwen and Glyn Grits as parts of a single formation, conformable with the rocks above and below; but, if we judge from the fossil as well as from the lithological evidence, the formation is more closely related to the Ordovician than to the Silurian. Further reference to this is made on pp. 190 & 191 in describing their equivalent farther north.

Relation of the Ashgillian to the Caradocian.
(See Table II., p. 189, & fig. 3, p. 185.)

The relation of the Ashgillian to the Caradocian in the North Berwyns may now be reviewed in the light of the facts set out in the preceding pages.

The hiatus shown by Dr. Groom & Mr. Lake to exist between the Dolhir Beds proper and the Caradocian Bryn Beds in the Glyn-Ceiriog region appears to be filled farther west by the Blaen-y-cym and Ty'n-y-twmpath Beds, the former yielding graptolites probably indicative of an Upper Caradocian age, and the latter containing a typical assemblage of Ashgillian trilobites.

The complete sequence appears to be developed at most places west of Gelli; but, east of that locality, the rapid diminution in thickness of the Dolhir Beds proper, that come to outcrop, and the absence of the Ty'n-y-twmpath[3] and the Blaen-y-cwm Beds, are best explained by faulting along a gently-dipping plane, a view put forward by Groom & Lake (see fig. 3, p. 185). This fault was described in detail as the Dolhir Fault, and was shown on their map as separating the Bryn and Dolhir Beds nearly as far west as Ty'n-y-twmpath. Our discovery of the Pen-y-Graig Ash west of Gelli and our present knowledge of the Blaen-y-cwm and

[1] Q. J. G. S. vol. lxiv (1908) pp. 572–73. [2] *Ibid.* p. 576.

[3] The available palæontological evidence is insufficient to prove or disprove the identity in age of the Dolhir Limestone and the Ty'n-y-twmpath Beds.

Table II.—Approximate Thicknesses in feet of the Formations from the Bryn Beds to the Corwen Grit, calculated from their Outcrops.

		Pen-Creigiau Barcut (western edge of Sheet 121).	Dolydd-Ceiriog (west of Nantyr).	Ty'n-y-twmpath (east of Nantyr).	Gelli (2 miles west of Glyn).	Glyn Valley (west side).	Glyn Valley (east side).	Pant.	Bryn.
Glyn Corwen Grit.	Upper or massive grit	20	20 ?	20	10	10—0	a	a	a
	Lower or platy grit and Glyn Limestone.	U	U	50	50 +	100—	20	20	20
Dolhir Beds (*sensu stricto*).		1860	1500	1020	1050	1000	970	840	620
Ty'n-y-twmpath Beds		300	180	150	U	U	U	U	U
Blaen-y-cwm Beds ……		120	90	100	50	a	a	a	a
Pen-y-graig Ash .. ……		a	10	20	4	10	a	a ?	a ?
Bryn Beds …………		120	150	210	210	360	400	500	560

[U=unrecognizable; a=absent. See also diagrammatic section, fig. 3, p. 185.]

Ty'n-y-twmpath Beds preclude us from accepting this wide range of the fault westwards, unless it passes to a lower horizon and cuts out the lower part of the Bryn Beds in this region, instead of the top, as suggested by Groom & Lake. The rapid westward thinning of the Bryn Beds might thus be accounted for; but there is no definite evidence for such a fault.

From Gelli eastwards, however, we have drawn a fault similar to that adopted by Groom & Lake, separating the Bryn Beds from the Dolhir Beds proper, and cutting out the Blaen-y-cwm and Ty'n-y-twmpath Beds; but in our view the Pen-y-graig Ash is probably absent by non-deposition east of the Glyn Valley, and most of the increase in thickness of the Bryn Beds is due to lithological changes affecting especially their lower part. In order to produce the arrangement of the outcrops observed, the fault must be inclined at a lower angle than the beds, and is probably a thrust.

The only other feasible explanation of the observed facts would involve an unconformity with overlap, or at least a marked non-sequence between the Ashgillian and the Caradocian beds east of Gelli. There is nothing, however, in the nature of the sediments composing the Ashgillian to suggest an unconformity. The gap in the sequence, also, is too extensive to be readily explained by a non-sequence.

Ashgillian Series north of the Llangollen Synclinorium.

Cyrn-y-Brain Beds and Plas-uchaf Grit.—The Ordovician inliers of Cyrn-y-Brain and Mynydd-Cricor are formed of greywacke-slates, sandstones, and grits, which can be correlated by their abundant fauna with the Dolhir Beds and the Glyn-Corwen Grit. Both inliers are anticlinal in structure, but the lowest beds exposed occur on Cyrn-y-Brain. Those have been detected north of Plas-uchaf, at one place only, and consist of soft micaceous sandstones, slightly cleaved and full of fossils. Above them follows a great thickness (probably 1500 feet at least) of cleaved gritty greywacke-slates, which, especially towards the top, become sandstones or grits. The Plas-uchaf Grit, which forms the summit of the series, is a massive uncleaved rock, from 10 to 20 feet thick on Cyrn-y-Brain, and quite comparable with the Corwen Grit. On Cyrn-y-Brain its highest part is composed of a tough platy sandstone with contorted lamination, about 3 feet thick, passing upwards with apparent conformity into a dark mudstone that weathers into a brown rottenstone. This may be taken as the base of the Valentian. On Mynydd-Cricor the thickness of the Plas-uchaf Grit varies greatly, and it appears to split and include bands of shale closely similar to the underlying cleaved greywacke-slates.

Throughout the Cyrn-y-Brain Beds, brachiopods are locally plentiful. Of these, *Meristina crassa* is the most characteristic and abundant form, occurring from top to bottom of the series. It was on account of the abundance of this fossil that the late Prof. T. McKenny Hughes[1] assigned the Plas-uchaf Grit (and presumably the underlying arenaceous beds) to the Llandovery Series. Our collections, however, prove that this brachiopod occurs here in association with undoubtedly Ordovician trilobites, such as *Trinucleus* and *Chasmops macroura*, the latter being of more frequent occurrence than *Trinucleus*.

The list of fossils given below (p. 191) shows that the Cyrn-y-Brain Beds, together with the Plas-uchaf Grit, are the equivalent of the Dolhir Beds proper and the Glyn-Corwen Grit.

Prof. O. T. Jones has pointed out to us that the types of *Plectambonites sericea* and of *Strophomena antiquata* found in the Cyrn-y-Brain Beds resemble those occurring in the Slade Beds of South Wales. The discovery of these forms, in shales interbedded with the Plas-uchaf Grit on Mynydd-Cricor, is useful evidence in favour of the Ordovician rather than of the Silurian age of that grit.

Orthis hirnantensis and *Strophomena siluriana* are most commonly found in, if not confined to, the upper part of the Cyrn-y-Brain Beds. These forms, in conjunction with *Orthis sagittifera* and *O. (Platystrophia) biforata*, var. *fissicostata*, point to a close comparison with the Hirnant Limestone and its associated rocks

[1] Q. J. G. S. vol. xxxiii (1877) p. 207.

which constitute the buffer formation between Ordovician and Silurian in the Bala country. In fact, Miss G. L. Elles[1] has expressed the opinion that the Hirnant Limestone is equivalent to the Conway-Castle Grits, the upper part of which she would regard as Llandovery in age.

List of Fossils from the Cyrn-y-Brain Beds.

[Fossils found in the Dolhir Beds are marked D, those in the Glyn Grit G. C indicates fossils found on Cyrn-y-Brain, and M on Mynydd-Cricor.]

D G *Favosites (Monticulipora) fibrosus* Goldfuss. Common. C.
D *Heliolites interstinctus* Linnæus. C.
D G '*Petraia*' *elongata* Phillips. C.
D *Petraia subduplicata* M'Coy. Common. C.
D *Petraia subduplicata*, var. *crenulata* M'Coy. C.
D G Crinoid-remains. C.
D Cf. *Caryocystites leitchi* Forbes. C.
D *Echinosphærites* cf. *baltica* Eichwald. C.
D *Phyllopora hisingeri* M'Coy. Common. C.
Pinacopora grayi Nicholson & Etheridge. C.
D G *Ptilodictya acuta* Hall. C.
Atrypa marginalis Dalman. M.
D G *Clitambonites ascendens* Pander. C.
? *Dinobolus* sp. M.
D G *Leptæna rhomboidalis* Wilckens. Common. C, M.
D *Lingula* sp. C, M.
Meristina crassa J. de C. Sowerby. Very common. C, M.
D G *Orthis actoniæ* J. de C. Sowerby. C.
D G *Orthis (Platystrophia) biforata* Schlotheim. C, M.
Orthis (P.) biforata, var. *fissicostata* M'Coy. M.
Orthis (P.) spiriferoides M'Coy. C ? M.
D G *O. calligramma (?)* Dalman. M.
D G *Orthis crispa* M'Coy. C.
D G *Orthis (Dalmanella) elegantula (?)* Dalman. C.
D *O. (D.)* cf. *testudinaria* Dalman.
D *Orthis hirnantensis* M'Coy. Common. C.
Orthis (Rhipidomella) cf. *mullockiensis* Davidson. C.
D G Cf. *Orthis (Plæsiomys) porcata* (M'Coy). C.
Orthis (P.) porcata, var. *sladensis* (Reed). C.
D *Orthis (Heterorthis ?) sagittifera* (M'Coy). C.
Parastrophia divergens Hall & Clarke. C.
Plectambonites papillosa Reed. M.
Plectambonites cf. *papillosa*. C.
D G *Plectambonites sericea* J. de C. Sowerby. C, M.
Plectambonites sericea, var. *rhombica (?)* M'Coy. C, M.
Rafinesquina expansa (?) J. de C. Sowerby. C.
'*Rhynchonella*' sp. C.
D *Strophomena antiquata* J. de C. Sowerby. C.
Strophomena siluriana Davidson. Common. C.
D *Triplecia insularis* Eichwald. C.
? *Zygospira* sp. C.
Murchisonia cf. *turrita* Portlock. C.
Murchisonia sp. C.
Tentaculites sp. C.
Acidaspis sp. C.
D *Calymene senaria* Conrad (Salter). Fairly common. C.
Calymene cf. *senaria*. C.
D *Chasmops macroura* Sjögren. Fairly common. C.
D *Encrinurus multisegmentatus*. Portlock. C.
Encrinurus sp. C.
D *Illænus bowmanni* Salter. C.
Illænus cf. *bowmanni*. C.
? D *Phacops brongniarti* Portlock. C.
Phacops sp. C.
Trinucleus sp. Rare. C.

[1] Q. J. G. S. vol. lxv (1909) pp. 183–84.

(C) Silurian: (*a*) The Valentian Formation.

Following with apparent conformity on the grits that constitute the summit of the Ordovician, is a series of cleaved, usually unfossiliferous, pale grey-green mudstones and shales[1] comprising the Llandovery and Tarannon 'pale slates' of earlier writers. These can be conveniently grouped as the Valentian Formation, and may be subdivided as follows:—

Upper Valentian or Tarannon (of Tarannon).
Lower Valentian or Birkhillian.

Dr. Groom & Mr. Lake studied these rocks first at Corwen,[2] and later at Glyn-Ceiriog,[3] where they gave the local names of 'Tydraw Slates' to the Tarannon and 'Fron-Frys Slates' to the Lower Valentian (their 'Llandovery'). We do not propose to adopt these names, because the sequence at Glyn-Ceiriog is very attenuated, and often shows signs of having been severely dislocated. It is probable that part of the Valentian is missing here, as a result of strike-faulting.

The fullest development of the Valentian in the region under description is brought to the surface by the anticlines of Cyrn-y-Brain and Mynydd-Cricor. This is summarized in Table III, opposite.

In the Cyrn-y-Brain area, the rocks are well exposed, but highly cleaved and much disturbed, and near Plas-uchaf, the eastern part of the World's-End Fault cuts out much of the lower series, and in its western part much of the Tarannon.

The palæontological evidence is very scattered. The chief data may now be given.

Lower Valentian.

The gritty grey-green mudstones with brachiopods are best seen in an old opening 130 yards north of Tai-newyddion, on the Ruthin road. Here were found:—

Atrypa reticularis Linnæus.
cf. *Meristina furcata* J. de C. Sowerby.
Orthis (Bilobites) biloba Linnæus.
Orthis calligramma Dalman.
Orthis (Dalmanella) elegantula (?) Dalman.
Orthis (Hebertella) protensa J. de C. Sowerby.
Orthis (Hebertella) sp.
Plectambonites cf. *duplicata* J. de C. Sowerby.
Plectambonites cf. *transversalis* Wahl.
Plectambonites sp. nov.
Plectambonites sp.
Trilobite.

This assemblage appears to represent a mixture of Lower and Upper Llandovery faunas; and, as elsewhere in the Llangollen district, is not very helpful for purposes of correlation. The rocks

[1] Where the rocks are referred to as shales or mudstones, the cleaved equivalent is implied.
[2] Q. J. G. S. vol. xlix (1893) p. 426.
[3] *Ibid.* vol. lxiv (1908) pp. 553–54.

TABLE III—THE VALENTIAN SEQUENCE: NORTH SIDE OF THE LLANGOLLEN SYNCLINORIUM.

	Zonal Classification.	Mynydd-Cricor.		Cyrn-y-Brain. Moel-y-faen district.		Cyrn-y-Brain. Plas-uchaf District.	
Wenlock.	*C. murchisoni.*	Banded blue slates.	*Feet.*	Banded mudstones.	*Feet.*	Banded mudstones.	*Feet.*
Upper Valentian or Tarannon of Tarannon.	*Monograptus crenulatus.*	Blue or banded mudstones and slates. *M. vomerinus* var. *crenulatus*, *Retiolites angustidens.*	About 1200	Splintery blue slates and mole-coloured mudstones. *M. vomerinus* var. *crenulatus* and *Retiolites angustidens.*	30	As in the Moel-y-faen district, but the maroon-coloured bands may coalesce. Much of the sequence is cut out by the World's-End Fault.	620? originally
	M. griestonensis.	Grey-green and striped mudstones. *M. griestonensis.*		Grey mudstones with brown streaks. *Phacops elegans*, *P. stokesi* and *Bilobites biloba.*	30		
				Maroon-coloured mudstones, usually in two bands separated by grey-green mudstones.	60		
	M. crispus.	Grey-green mudstones, with occasional bands of striped mudstones. *M. crispus* & *M. discus.*		Grey-green mudstones, with occasional bands of striped mudstones. Pyrites-cubes common. Occasionally the mudstones are cleaved severely and converted into sericitic slates. *M. discus.*	200		
	M. turriculatus.			Barren grey-green mudstones.	300		
Lower Valentian or Birkhillian.		Non-Sequence.		Non-Sequence.		Non-Sequence.	
	M. convolutus.	Absent.		Black graptolitic mudstone. *M. convolutus* (? sometimes absent).	3	Black mudstone and dark-grey shale, with poorly-preserved graptolites.	50?
	M. gregarius.	Absent.		Dark graptolitic slate (thin), ? *gregarius* zone, on gritty grey-green mudstones with sandy seams. Brachiopods.	330	Maroon-coloured slates and gritty green slates, often micaceous and yielding a few brachiopods.	
	M. cyphus.	Thin black mudstone.	2			Gritty grey-green mudstones containing some brachiopods.	800?
	? *Mesograptus modestus.*	*M. cyphus* on mottled grey-green slates with sandy laminæ.	500 to 600	Unfossiliferous grey-green mudstones and slates, the upper part showing streaks of pyrites on the cleavage-planes, the lower part often speckled with white blotches.	350 to 400	Grey-green mudstones and slates, with streaks of pyrites on the cleavage-planes.	
	? *Cephalograptus acuminatus.*					Compact greenish mudstone yielding a few brachiopods.	10
						Black sandy mudstone weathering to rottenstone.	5
Ashgillian.		Greywacke-mudstones and grit.		Massive grit (Plas-uchaf Grit).		Platy and massive grit (Plas-uchaf Grit).	

which yield this fauna lie not far below the top of the Lower Valentian.

It is, however, uncertain whether the upper limit of the Lower Valentian always occurs at the same horizon in these northern outcrops. The summit near Hafod-yr-Abad, for example, is formed by shales which 120 yards east of the house yielded the following graptolites, indicating the zone of *Monograptus convolutus*:—

Climacograptus scalaris Hisinger.
C. tornquisti Elles & Wood.
Diplograptus (Orthograptus) bellulus Tornquist.
Diplograptus (Mesograptus) magnus H. Lapworth.
Diplograptus (Glyptograptus) tamariscus Nicholson.
Monograptus argutus Lapworth.
M. convolutus Hisinger.
M. decipiens Tornquist.
M. leptotheca Lapworth.
M. lobiferus M'Coy.
M. regularis Tornquist.
M. sedgwicki ? Portlock.
M. undulatus Elles & Wood.

These are well preserved. The outcrop of the soft shale in which they occur forms a depression which has been taken as a line of division between the Upper and the Lower Series.

On the other hand, at the summit of the Lower Series on the moor road, 400 yards north-east of Bryn-yr-odyn, graptolites in a bad state of preservation were found, which suggest the zone of *M. gregarius*. But the reference of the rocks to that zone is not absolutely reliable. The list is as follows:—

Climacograptus rectangularis (?) M'Coy.
C. tornquisti Elles & Wood.
Diplograptus (Mesograptus) magnus H. Lapworth.
Monograptus atavus Jones.
M. gregarius Lapworth.
M. revolutus Kurck., var. *austerus* Tornquist.
M. triangulatus Harkness.

One other feature of the Lower Valentian on Cyrn-y-Brain must be noted: namely, the absence (except at one place) of the speckled variety of mudstone so characteristic of that formation in the other districts.

Upper Valentian.

In the Tarannon Series on Cyrn-y-Brain, the lowest beds are unfossiliferous, except near Llandegla, where at a point 600 yards west of Hafod-Bilston, *Monograptus becki* Barrande, *M. marri* Perner, and *M. runcinatus* Lapworth, suggest a horizon about the zone of *M. turriculatus*. The presence of the *M.-crispus* Zone is well established by the following forms from the roadside 20 yards south-west of the barn at Ty-uchaf, a quarter of a mile south of Bryn-yr-odyn:—

Monograptus discus Tornquist, common.
M. griestonensis Nicol.
M. marri Perner.
Monograptus nudus Lapworth.
M. pandus Lapworth.
M. planus Barrande.
M. spiralis Geinitz.

And the following from the farmyard at Hafod-yr-Abad :—

Monograptus runcinatus Lapworth.
M. nudus Lapworth.
M. exiguus Nicholson.
M. turriculatus Barrande.
Monograptus pandus Lapworth.
M. nodifer Tornquist.
M. priodon Bronn.

This assemblage indicated a low position in the *M.-crispus* Zone.

The deposits overlying the *M.-crispus* Zone may represent the *griestonensis* beds, and are interesting on account of their occasional trilobite and brachiopod remains. In the steep lane heading from the old Ruthin road to Pentre-uchaf, half-a-mile south of Bryn-yr-Odyn, the following forms were collected :—

Favosites sp.
Orthis (Bilobites) biloba Linnæus.
Phacops cf. *elegans* Sars & Bœck.
Phacops stokesi Milne-Edwards.
Phacops sp.

The *M.-crenulatus* Zone is characterized by its peculiar lithology (dark slates and mudstones), which easily distinguishes it from the pale slates below, and the banded and laminated mudstones and slates of the overlying Wenlock. It occupies, as a result of gentle folding, a wide strip of country near the Moel-y-faen quarries.

The following forms were found at a point 300 yards north of Fron-adda on the side of the old Ruthin road :—

Monograptus griestonensis Nicol.
M. vomerinus Nicholson, var. *crenulatus* Tornquist.
Retiolites (Gladiograptus) geinitzianus Barrande var. *angustidens* Elles & Wood ;

while, on the old tram-line 340 yards north-west of Fron-adda, an abundance of *M. vomerinus* var. *crenulatus* is found. This outcrop appears to be part of a faulted inlier.

The Mynydd-Cricor Area.

In this district the Valentian, as a rule, dips outwards from Mynydd-Cricor in conformity with the anticlinal structure, but it is much affected by faults. Near Ffynnon-Tudur there is also considerable thrusting, and the general dip is reversed in the Tarannon Beds that override the Lower Valentian Series, so that Wenlock Beds lie against the Ordovician on the west side of Cricor.

Lower Valentian.—The Lower Valentian rocks of Mynydd-Cricor exhibit the typical speckled and pale grey-green aspect, and are rarely fossiliferous. The following forms were collected from Bryn-Rhedyn, 1 mile east by south of Cricor Farm :—*Plectambonites scissa* Salter and ? *Strophomena* cf. *fletcheri* Davidson.

The summit of the Lower Series appears to be in the zone of *M. cyphus*, for the following forms occur, within a few feet of typical Tarannon mudstone in the ravine, half a mile south-east

o 2

of Cricor Farm, and we can find no evidence of the junction being faulted :—

Climacograptus rectangularis M'Coy.
Diplograptus (Glyptograptus) tamariscus Nicholson.
Monograptus acinaces (?) Tornquist.
Monograptus atavus (?) Jones.
Monograptus cyphus Lapworth.

Upper Valentian.—In the Upper, or Tarannon, Series, no fossils indicative of the *turriculatus* zone have come to light, but the rocks that may be referable to it are very unfossiliferous. The exposure yielding the above-mentioned *M.-cyphus* Zone fossils is separated from an outcrop of the *M.-crispus* Beds by the north-and-south Tan-y-graig Fault. Near the little reservoir here seven fossiliferous localities were discovered in a thickness of some 300 feet, in dark striped bands intercalated in the usual grey-green mudstone. The upper part may represent a portion of the zone of *M. griestonensis*, but the following forms occurring near the reservoir indicate the *M.-crispus* Zone :—

Monograptus crispus Lapworth.
M. discus Tornquist.
M. griestonensis Nicol.
M. marri Perner.
M. nodifer Tornquist.
Monograptus pandus Lapworth.
M. priodon Bronn.
M. runcinatus Lapworth.
M. spiralis Geinitz.

The presence of the *griestonensis* beds, followed by the darker and often striped *crenulatus* passage-beds up into the Wenlock Series, has been established at several places in this area. Near Nant-uchaf, three-quarters of a mile south of Cricor Farm, we find *Monograptus* cf. *griestonensis* Nicol, *M. marri* Perner, and *M. spiralis* Geinitz, 210 yards to the north-east; also *M. priodon* Bronn, *M. vomerinus* var. *basilicus* Lapworth, and var. *crenulatus* Tornquist, about 110 to 130 yards south of that farm.

In the ravine half a mile north-north-east of Rhos-lydan the following forms, in Miss G. L. Elles's opinion, probably indicate the zone of *Monograptus griestonensis* :—

Monograptus crispus Lapworth.
M. discus Tornquist.
M. griestonensis Nicol.
M. marri Perner.
Monograptus nudus Lapworth.
M. pandus Lapworth.
M. priodon Bronn.

In Nant-y-garth the passage-beds (*M.-crenulatus* Zone) are admirably exposed about a third of a mile west-north-west of the 6th milestone from Ruthin, and yielded *Monograptus priodon* Bronn, *M. vomerinus* Nicholson, var. *crenulatus* Tornquist, and *Retiolites (Gladiograptus) geinitzianus* Barrande, var. *angustidens* Elles & Wood.

Southern Limb of the Llangollen Synclinorium.

On the south side of the Llangollen Synclinorium the Valentian succession is even more obscure than in the north. The whole group of rocks is much reduced in thickness, and is very unfossiliferous.

Corwen-Moel-Fferna Area.

In the Corwen-Moel-Fferna district the following appears to be the sequence :—

Wenlock.	*Cyrtograptus-murchisoni* Zone.	Banded slates.
Upper Valentian or Tarannon.	? *Monograptus-crenulatus* Zone.	Dark, splintery, blue slate and banded slate.
	? *M.-crispus* Zone.	Grey-green sandstone and slates, with pebbles or nodules of limestone in places.
	M.-turriculatus Zone.	Striped and grey-green slates.
Lower Valentian or Birkhillian.	*M.-convolutus* Zone.	Dark mudstone yielding graptolites.
		Grey-green gritty slates, in places speckled, and interbedded, especially near the base, with thin sandstone-bands.
Ashgillian.	Corwen Grit.	

There is no apparent unconformity at the base of the Valentian. The *convolutus* zone was determined by Dr. Groom & Mr. Lake[1] in Nant-Llechog. Near the Corwen slate-mine, and at the head-waters of the Ceiriog, forms were found by us indicating the *turriculatus* zone :—

	1	2
Climacograptus extremus H. Lapworth.	×	
Monograptus becki Barrande.	×	
M. dextrorsus Linnarsson.	×	
M. exiguus Nicholson.	×	
M. gemmatus Barrande.	×	
M. priodon Bronn.		×
Monograptus marri Perner.	×	×
M. nudus Lapworth.	×	×
M. pandus Lapworth.	×	×
M. runcinatus Lapworth.	×	×
M. turriculatus Barrande.	×	
M. halli Barrande.		×
Retiolites geinitzianus Barrande.		×

1 = Head-waters of the Ceiriog, south side of Moel-Fferna.
2 = In stream 330 yards north-west of the Corwen slate-mine, near Carrog.

There is no great thickness of rock between the *convolutus* and the *turriculatus* zones, and no appearance of unconformity.

The Glyn-Ceiriog Area.

In this area Dr. Groom & Mr. Lake's map and description of the Valentian succession have been confirmed in the main. The conformable upward succession from the Glyn Grit was proved by them, and can be studied in quarries and natural exposures near

[1] Q. J. G. S. vol. xlix (1893) pp. 432–33.

the Nant-Ty'n-y-twmpath stream, in the neighbourhood of the Glyn-Ceiriog–Glyn-Dyfrdwy road.

The following appears to be the sequence in this area:—

SECTION UP THE NANT TY'N-Y-TWMPATH.

		Thickness in feet.
Wenlock.	Banded earthy-weathering slates. *Cyrtograptus-murchisoni* Zone.	
Tarannon or Upper Valentian (Ty-draw Slates).	(5) Blue slates, interbedded in the lower part with grey mudstone of the Tarannon type. *Monograptus-crenulatus* Zone	10
	(4) Grey-green mudstone, with occasional striped bands, cleaved into thick roofing-slates .... about	140
Lower Valentian (Fron Frys Slates).	(3) Pale gritty shale, with brachiopods.	6
	(2) Speckled or mottled, rather gritty green slates	70
	(1) Platy sandstone with shale-bands, passing down into more thickly-bedded sandstone	2
Ashgillian.	Glyn Grit.	

In the Lower Valentian no graptolites have been found, but in places brachiopods are fairly numerous. Although for the greater part these are Lower Llandovery forms, yet some, in Prof. O. T. Jones's opinion, are more typical of the Upper Llandovery. The following forms were identified by him. Fossils collected from a point 120 yards south-east of Cefn-isaf, near Glyn-Ceiriog, were:—

Camarotœchia borealis Schlotheim.
Catazyga (?).
Leptæna rhomboidalis Wilckens.
Leptæna sp. nov.
Meristina furcata J. de C. Sowerby.
Meristina subundata M'Coy.
Meristina sp.
Orthis (Bilobites) biloba Linnæus.
Orthis (Hebertella) protensa J. de C. Sowerby.
Orthis cf. *rustica* J. de C. Sowerby.
Orthis (Dalmanella) sp.
cf. *Orthotetes pecten* Linnæus.
Pentamerus globosus J. de C. Sowerby.
Plectambonites duplicata J. de C. Sowerby.
Plectambonites scissa Salter.
Plectambonites cf. *transversalis* Wahl.
Acidaspis sp.

In an old quarry on the right bank of the Nant-Ty'n-y-twmpath the following were discovered:—

Catazyga (?).
Meristina cf. *subundata* M'Coy.
Orthis (Dalmanella) sp.
Plectambonites scissa Salter.
Plectambonites cf. *transversalis* Wahl.

The brachiopods enumerated above occur in the uppermost part of the Lower Valentian.

In the Upper Valentian a few graptolites have been discovered.

The *crenulatus* beds are recognizable here, as elsewhere, by their dark-blue colour, at the summit of the Tarannon pale slates. The following fossils were found at Nant-Fowc, a mile and a half south-east of Glyn-Ceiriog:—*Monograptus vomerinus* Nicholson, and *M. vomerinus* var. *crenulatus* Tornquist.

The presence of the *griestonensis* zone is suggested by the

following forms from 450 yards north of Fron-Llwyd:—*M. griestonensis* Nicol, *M. marri (?)* Perner, and *M. priodon* Bronn.

From the data here brought forward it is clear that the 'Pale Slates' of Glyn-Ceiriog are undoubtedly of Valentian age; yet it is obvious that we have but little precise information as to their zonal position. Their remarkable thinness, coupled with the quartz-veining and disturbance of the Tarannon Slates, especially well seen near the Glyn slate-quarries, suggests that the strata observed at the outcrop do not represent the true development of the formation.

Summary of the Valentian Sequence.

It is now possible to give a conspectus of the Valentian formation in the whole district.

The fullest development is seen in the northern outcrops of Mynydd-Cricor and Cyrn-y-Brain, while, though thinner near

TABLE IV.

a=absent; i=inferred; p=proved.		Glyn-Ceiriog.	Moel-Fferna and Corwen.	Cyrn-y-Brain and Llandegla.	Mynydd-Cricor.
Tarannon	*Monograptus crenulatus*	p	p	p	p
	M. griestonensis	p	i	p ?	p
	M. crispus	i	p	p	p
	M. turriculatus	?	p	p	i
	Thickness in feet	120 to 150	200 to 300	700 to 900	1200 ?
	Non-sequence.				
Birkhillian	*M. sedgwicki*	a	a	a	a
	M. convolutus	? a	p	p	a
	M. gregarius	? a	i	p	a
	M. cyphus	? a	i	i	p
	Orthograptus vesiculosus with *Mesograptus modestus*	i	? p	? p	i
	Climacograptus acuminatus	i	i	i	i
	Thickness in feet	80 to 120	350 ?	900 ?	500 to 600 ?

Corwen, the series is even there far more imposing than at Glyn-Ceiriog.

Owing to the difficulty of collecting and identifying the fossils, to the monotonous lithology, and to the movements that the beds have undergone, it is not possible to dogmatize concerning the presence or absence of some parts of the series; but it does appear probable that the thinness noted at Glyn-Ceiriog may be in part due to faulting, though chiefly to attenuation of the sediments.

Over the greater part of the district evidence seems to exist for

the original deposition of all the usually accepted zones of the Tarannon Series. These have a peculiar lithology that in practice, as a rule, suffices to differentiate them from the lower series. The relationship of the Tarannon to the Lower Valentian or Birkhillian still remains obscure. It is probably in the nature of a non-sequence, for there are no signs of an unconformity in the type of sediment, yet the *Monograptus-sedgwicki* Zone has nowhere been observed, and the Tarannon slates appear to rest in places on the *convolutus* zone (Corwen and parts of Cyrn-y-Brain) and in places on that of *M. gregarius* (parts of Cyrn-y-Brain) or of *M. cyphus* (Mynydd-Cricor).

Table IV on p. 199 illustrates the development of the usually recognized Valentian zones in the various areas dealt with.

(*b*) Salopian Formation—The Denbighshire Series.

(1) General Observations.

In the course of the present investigation some 70 square miles of the outcrop of the Wenlock and Ludlow Series have been mapped. The rocks comprise the 'Denbighshire Series' of previous workers.

The Langollen-Corwen district has been dealt with by various workers from the days of J. E. Bowman[1]; but they have, for the greater part, confined their attention to the simple southern portion of the synclinorium.

In 1895 Mr. P. Lake[2] put forward the following classification :—

Dinas-Brân Beds.
Slaty Beds, with *Monograptus leintwardinensis*.
Gritty Beds.
Flags, with *Monograptus colonus*, *Cardiola interrupta*, *Orthoceras primævum*, etc.
Moel-Fferna Slates, with *Monograptus flemingi*, *M. priodon*.
Pen-y-glog Grit.
Pen-y-glog Slates, with *Monograptus personatus*, *M. priodon*, etc.

Subject to modifications to which reference is made in the sequel, this classification, together with zonal information contained in the papers by Miss G. L. Elles and Dame Ethel Shakespear (*née* Wood), mentioned on p. 177, has formed the basis of our work.

That the strata of the Denbighshire Series are of shallow-water origin is suggested by the great thickness of rocks of one lithological type, and by the presence of internal brecciation, cross-bedding, and contemporaneous erosion-phenomena.

The series is probably between 4000 and 5000 feet thick, and is composed (with the exception of the Pen-y-glog Grit) of what

[1] Brit. Assoc. Rep. of Sections (Glasgow) 1840, p. 100; *ibid.* (Plymouth) 1841, p. 59; and Trans. Manchester Geol. Soc. vol. i (1841) p. 194.

[2] Q. J. G. S. vol. li, pp. 9–22. This paper contains a bibliography complete up to 1895.

were originally bands of laminated silt, alternating with bands of mud. The thickness of individual layers varies from perhaps 1/10 inch to several inches, or occasionally a foot or more, but the monotonous alternation persists throughout. Except in the Pen-y-glog Slates, the mud-bands usually exceed the silt-bands in thickness, and there appears to be a fairly constant thickness-ratio of about 1 to 3 or 1 to 5, as between silt-band and mud-band as measured now in the indurated and cleaved condition. There is little doubt that the alternations represent seasonal variations of the transporting power of the rivers which supplied the sediment to the sea.

The mud-bands have assumed a more or less perfect cleavage; but the silt-bands are frequently devoid of it, although in many cases the cleavage passes through both. This factor, together with the original thickness of the bands, and the angle between the dip of cleavage and the bedding, produces an endless variety of appearance within somewhat monotonous limits.

Apart from the Pen-y-glog Slates and Grit no subdivision of the group possesses any striking lithological characteristic by which it can be readily identified and traced. Nor do the fossils give much help, on account of their rarity and poor preservation. Hence there is considerable doubt about the accuracy of the lines representing the boundaries of the subdivisions of the Salopian shown in the map (Pl. V), which must be regarded as illustrating the structure, and as offering a solution (admittedly imperfect) to the riddle of the folding (see pp. 212–17), in the complex Llangollen Synclinorium.

It appears probable that most of the accepted graptolite-zones of the Wenlock and Lower Ludlow (as developed in the Welsh Borderland, Shropshire, and elsewhere) are represented. The general sequence and the zones are indicated in Table V (p. 202).

(2) Wenlock Series.

The Wenlock is thin in comparison with the Lower Ludlow Series, and is relatively well known.[1] Its lowest member, comprising mudstones and slates with the fauna of the *Cyrtograptus-murchisoni* Zone, succeeds the *Monograptus-crenulatus* Beds of the Upper Valentian conformably.

The lithology of this and the succeeding *M.-riccartonensis* Zone may be described as banded earthy-weathering slates,[2] the upper zone providing the roofing-slates of Glyn-Ceiriog, Moel-Fferna, Pen-y-glog (Corwen Slate-Mine), and Moel-y-faen. In the southern part of the district the roofing-slates are succeeded by

[1] G. L. Elles, Q. J. G. S. vol. lvi (1900) p. 397; P. Lake, *ibid.* vol. li (1895) pp. 9–22.

[2] They are of interest, on account of the problematical fossil *Berwynia carruthersi* (a plant of unknown affinities, now preserved as an anthracitic substance).

TABLE V—THE DENBIGHSHIRE SERIES.

	Proposed Sub-divisions.	Zonal Classification.	Moel-Fferna Area.	Feet.	Llangollen-Glyn-Ceiriog Area.	Feet.	Llantisilio Mountain.	Feet.	Area north-west of the Bryn-eglwys Fault.	
? Upper Ludlow Series.	Dinas-Brân Group.	*Dayia navicula.*			Sandy uncleaved shale.				? Banded flags of Moel-yr-Acre.	
Lower Ludlow Series.	Vivod Group.	*Monograptus leintwardinensis.*			Sandstones and gritty mudstones.	1200 to 1300			Banded concretionary slates and mudstones.	
	Nant-y-Bache Group.	*? M. tumescens.* *M. scanicus.*	Fine-grained sandstones (often internally crumpled) and slates.		Fine-grained sandstones (often internally crumpled) and slates.	900	Fine-grained sandstones (often internally crumpled) and slates.	900	Platy flags, shales, and mudstones.	Thicknesses cannot be determined.
	Glyn-Dyfrdwy Group.	*M. nilssoni.* *? M. vulgaris.*	Flags and slates. Slab-horizon (shale). Flags and slates. Pentre-Dwfr Slates (north of the Dee).		Flags and slates. Slab-horizon (shale). Flags and earthy-	1100+	Flags and slates. Slab-horizon (shale). Flags and slates. Pentre-Dwfr Slates. Flags and slates.	1000 650 to 700	Flags and slates with rottenstone concretions.	
Wenlock Series.	Pen-y-glog Group.	*? Cyrtograptus lundgreni.*	Flags, slates, and dark-blue gritty slates. Pen-y-glog Grit.	0 to 120	weathering slates.		Dark-blue slates.	? 100	Zones not identified. Blue, calcareous, cleaved shales and gritty mudstones. Pen-y-glog Grit (north-west of Bryneglwys). Laminated gritty shales, zones not identified.	
		C. linnarssoni.	Bastard, earthy-weathering banded slates.	65 to 70	Bastard, earthy-weathering banded slates.	90	Bastard, earthy-weathering banded slates.	250 ?		
		Monograptus riccartonensis.	Pen-y-glog Roofing-slates (banded).	55 to 60	Pen-y-glog Roofing-slates (banded).	57	Pen-y-glog Roofing-slates (banded).	60 ?	Banded mudstone and slates.	
		Cyrtograptus murchisoni.	Banded slates.	15 ?	Banded slates.	15 ?	Banded mudstone.	15 ?		

'bastard slates' which have yielded the following graptolites indicative of the zone of *Cyrtograptus linnarssoni*:—

	1	2		1	2
Cyrtograptus linnarssoni Lapworth.	×		*Monograptus flexilis* Elles.	×	×
Cyrtograptus symmetricus Elles.	×		*M. priodon* Bronn.	×	×
Monograptus dubius Suess.		×	*M. vomerinus* Nicholson.	×	×
M. flemingi Salter.		×	*M. vomerinus* var. *basilicus* Lapworth.	×	
M. flemingi var. *primus* Elles & Wood.		×			

1 = North side of the quarry, north of the upper bridge over the Nant Ty'n-y-twmpath.
2 = Level in Moel-Fferna Slate-Quarry.

It was the presence of this fauna at Moel-Fferna that led Mr. P. Lake to institute his 'Moel-Fferna Slates'; but the present development of the mine clearly demonstrates that the 'bastard slates' (with *C. linnarssoni*) lie under, and not over, the Pen-y-glog Grit as he thought.

Pen-y-glog Grit occurs only in the western part of the district. It is a tough, fairly massive, felspathic grit, often interbedded with hard blue shale. Miss G. L. Elles states that the grit overlies the *M.-riccartonensis* Beds at Pen-y-glog. If this be so, the base of the grit lies at a lower horizon there than at Moel-Fferna, a fact that may perhaps be related to its greater thickness at the former place, where it is perhaps 120 feet thick. It thins to 30 feet at Moel-Fferna, and cannot be traced far to the east of this point. A similar eastward thinning occurs in its northern outcrop near Ffynnon-Tudur (north-west of Bryneglwys), an occurrence of the grit that was overlooked by the makers of the old geological map.

In the Moel-Fferna district the grit is overlain by hard dark-blue slates, devoid of fossils, which in turn give place upwards to slates and silty bands of the Lower Ludlow type. But in Glyn-Ceiriog there is no trace of the grit, and a considerable thickness of banded, earthy-weathering, 'bastard slates' succeeds the roofing-slates; we only know that, near the Nant-Ty'n-y-twmpath, the lower part of these represents the *linnarssoni* zone (see above).

It appears that the junction with the Lower Ludlow is possibly cut out in places by the Glyn-Ceiriog and Nant Ffrydd-isel Faults, but the evidence is meagre and difficult to interpret.

In addition to the almost continuous outcrop on the south and west side of the Llangollen Synclinorium, the Wenlock deposits emerge at Caer-Drewyn Hill, north-east of Corwen (see p. 216), north and north-east of Bryneglwys, and on the south side of Cyrn-y-Brain. In the last-named area they have been extensively quarried in the past, on Moel-y-faen in particular. There is a general similarity of lithology here and in the southern outcrop; but, on account of severe folding, and because the cleavage often crosses the bedding more or less at right angles, the sequence and

fossils are not so easily studied. The following appears to be the succession :—

	Thickness in feet.
Slates and silty sandstones of Lower Ludlow type.	
Gritty blue slates, with occasional trilobites and *Orthoceras*	? 100
'Bastard' banded slates, with a 20-foot bed, near the base, composed of brecciated blocks of laminated shale set in a blue shaly matrix, the whole being well cleaved	? 250
Banded roofing-slates, with beds of spar........................	? 60
Banded mudstone, yielding fossils of the *Cyrtograptus-murchisoni* Zone......	? 15 to 20

The brecciated bed mentioned above may be seen in an old quarry near Cae'r-hafod, and also near Ty-cerrig. The blocks of shale composing it are disposed in every direction, as revealed by the lamination; but the normal cleavage goes through all, without reference to the orientation of the blocks. The band provides evidence of considerable consolidation of the silts and muds soon after their deposition—in fact, before the laying-down of the succeeding beds of shale. Brecciation within a bed the upper and lower surfaces of which are sub-parallel, and possess the same dip as the neighbouring rocks, seems to point to penecontemporaneous disturbance, perhaps by an earthquake, on similar lines to those suggested by Prof. P. F. Kendall.[1]

In the Bryneglwys area, the Wenlock deposits are blue and banded slates; but, as they have not been exploited, little can be made out of the detailed succession. The *Cyrtograptus-murchisoni* Zone, however, has been detected at points near the Tarannon-Slate outcrops. The structure of this area is dealt with on p. 211.

(3) Lower Ludlow Series.

(*a*) The Ludlow Series in the Llangollen Synclinorium.

(i) Glyn-Dyfrdwy Group.—In the southern part of the synclinorium there is no lithological feature and practically no palæontological evidence on which to draw the base of the Lower Ludlow Series. It is probable that the bottom part of the Glyn-Dyfrdwy Group is absent through faulting in the Glyn-Ceiriog valley; and, if present farther west, it is poorly exposed on the moors. Near Carrog and Moel-Fferna the normal upward sequence from the Pen-y-glog Grit appears to be interrupted by a north-and-south fault along the Nant Ffridd-isel, which cuts out the basal part of the group.

Could we but study this basal member adequately, it would probably be found to fall in the zone of *Monograptus vulgaris* which Dame Ethel Shakespear believed that she could recognize in

[1] Abs. Proc. Geol. Soc. 1918–19, p. 28; see also B. Smith, Geol. Mag. 1916, pp. 146–56.

the Nant-Arddau Valley (Nant-y-Pandy), south of the Dee-side Slab-quarries. Unfortunately, our collecting has not provided material enough to confirm or disprove the existence of this zone.

On the northern flank of the synclinorium, there appears to be a complete upward sequence from the Wenlock Series into slates with thin silty sandstones, but there is no reliable palæontological evidence by which to distinguish the two formations. There is here, above the doubtful series, a well-marked slate-band (the Pentre-Dwfr Slates) the outcrop of which we have tried to represent on the map (Pl. V). The slates are not recognizable south of the Dee: they may, however, be cut out by the faulting mentioned above. As roofing-slates they have good weathering properties, but are too thick for modern requirements. The cleavage passes indiscriminately through mudstone and laminated silts in which uncleaved calcareous concretions are frequent. The slates pass upwards into an indefinite series of slates with thin silty sandstone-bands.

The succeeding 'Slab Horizon' is traceable throughout the synclinorium with fairly constant lithological characters. The subdivision is essentially composed of rapidly alternating bands of cleaved mudstone and uncleaved laminated silt. When not broken up by close jointing, the rock splits readily between the cleaved and uncleaved layers into huge slabs of a uniform thickness, and has formerly been extensively quarried for slate-slabs, stone-cisterns, flags, etc.[1] As the graptolite fauna of this horizon has been shown by Dame Ethel Shakespear[2] to be that of the *Monograptus-nilssoni* Zone, and, as other striking features of the fauna (the local abundance of '*Actinocrinus*' *pulcher*[3] and of '*Orthoceras primævum*') have long been known, it is unnecessary to go into further details. Our fossil-collecting confirms the reference of the slabs to the *nilssoni* zone.

The uppermost subdivision of the Glyn-Dyfrdwy Group is composed of fairly thin-bedded shales and silty mudstones or sandstones, occasionally micaceous, more or less perfectly cleaved. The sandstones are sometimes internally crumpled, and the shales frequently show concentric staining very similar to that seen in the Moughton Whetstone of the Austwick Valley (Yorkshire). The group as a whole is rather conspicuously unfossiliferous, but a few graptolites have been found on the hills south-west and south of Glyn-Dyfrdwy and elsewhere, which suggest that the rocks form part of the *Monograptus-nilssoni* Zone.

There are fine exposures in this group on the hillside north of the bridge over the Dee at Glyn-Dyfrdwy, and north-west of Dolywern near Glyn-Ceiriog.

In the latter area the subdivisions of the Glyn-Dyfrdwy Group

[1] Flags of this rock, with the characteristic fossils, have been found in the Roman Camp near Capel-Curig.

[2] Q. J. G. S. vol. lvi (1900) p. 446.

[3] D. W. Roberts, Trans. Edin. Geol. Soc. vol. i (1870) p. 329.

appear to have the following thickness, although the lowest member is in part cut out by the Glyn-Ceiriog Fault:—

	Feet.
Uppermost group	600
Slab horizon	270
Lowest group (part)	240 ?

The thickness is not so easily measured in the disturbed northern part of the synclinorium, but may be approximately 1600 to 1700 feet.

(ii) Nant-y-Bache Group.—In this group the rocks are predominantly uncleaved silty sandstones and roughly-cleaved sandy shales. They are best studied south of the Llangollen Fault, where they occupy most of the upland between the Dee and Ceiriog drainages, east of Glyn-Dyfrdwy. North of the fault, they are involved in the severe folding, and therefore, although well developed, they are more difficult to investigate. The group appears to be approximately 900 feet thick.

The base of the group has been taken to be the lower limit of somewhat calcareous and (as a rule) internally-crumpled[1] silty sandstones, which form a bold escarpment from near Foel, past Glyn-Ceiriog and Dolywern, to the Ceiriog valley near Pont-fadog, where they cross to the eastern side and form the nameless hill 1330.

Near Dolywern and Glyn-Ceiriog a calcareous conglomerate of rounded blue sandstone-pebbles, with a few shale-fragments and many small blackish pebbles, occurs in the lowest part of the group. It varies from $2\frac{1}{2}$ feet to about 1 inch in thickness. A search for fossils in the pebbles revealed only one *Orthoceras*, though their lithology is suggestive of the Teirw Beds. The significance of the conglomerate is not known, but it appears to be an indication of renewed uplift along the Berwyn axis (see p. 183).

Associated with crumpled sandstones are fossiliferous layers, often crowded with *Monograptus chimæra*, *M. dubius*, and *M. tumescens (?)*, while occasionally small brachiopods are very abundant in calcareous bands that weather to rottenstone. North of Dolywern, the following forms were found:—*Atrypa reticularis* Linnæus, *Dayia navicula* J. de C. Sowerby, and *Orthis* (*Dalmanella*) sp. In slightly higher beds in the same area *Cardiola* (*Slava*) *interrupta* J. de C. Sowerby is fairly common.

There are extensive exposures of the Nant-y-Bache Group in the stream from which it takes its name and in the other branches of the Cyflymen Brook, which descends towards Llangollen, although here no fossils have been found. The rocks are predominantly sandy; but there is also some sandy, poorly cleaved shale.

[1] We term the structure 'internal crumpling,' because it can be seen in many cases that a bed, say, a foot thick, preserves its upper and lower surfaces sub-parallel and seemingly undisturbed, while within there is folding and even overfolding. The more shaly bands interstratified with the sandstones are roughly cleaved. Less conspicuous internal crumpling occurs in the sandstones of the uppermost Glyn-Dyfrdwy Beds.

The uppermost beds of the group form the south side of the Pengwern Valley. Here, about 200 yards south by east of Ty'n-y-celyn the following assemblage, possibly indicating the lower part of the *Monograptus-scanicus* Zone, was found:—

Monograptus chimæra Barrande.
M. chimaera, var. *salweyi* Lapworth.
M. colonus Barrande.
Monograptus dubius Suess.
M. varians Wood.

These beds are some 300 to 400 feet below the lowest horizon at which *Monograptus leintwardinensis* has been found.

On the north side of the Llangollen Fault the Nant-y-Bache Group is involved in the severe folding (Pl. V).

(iii) Vivod Group (*M.-leintwardinensis* Beds).—The rocks composing this group are largely thinly-bedded flaggy shales with silty, often laminated bands at frequent intervals. They are less well cleaved than any of the rocks so far dealt with, the result (it is believed) of their sandy nature. Fossils are rare in them, but *M. leintwardinensis* has been found at several places. The group is perhaps 1200 to 1300 feet thick.

South of the Llangollen Fault the characteristic fossil was discovered at Craig-y-dduallt (south of Pengwern) and near Pant-Dafydd-goch, and probably all the high land between the Castle-Mills Fault and the Carboniferous of Chirk Castle is occupied by this group.

North of the Llangollen Fault, the rocks underlying the Vivod Valley, Berwyn,[1] and part of Llangollen itself appear to belong to this subdivision.

The lateral shift effected by the branches of the Llangollen Fault is well shown by the outcrops of the beds; but the exact distribution of the rocks east of Llangollen is very obscure.

(*b*) Lower Ludlow Rocks outside the Llangollen Synclinorium.

The stratigraphy of the Lower Ludlow inside the Llangollen Synclinorium has been dealt with at some length, because the mutual relationship of the beds is clearer here than elsewhere in the area under description. There seems, however, little doubt that the rocks maintain the same general characters outside the synclinorium, and there is palæontological evidence that the usual zones are present. Thus:—The *M.-leintwardinensis* Zone, indicating synclinal cores, is found south of Moel-Truan, near Bryn-Tangor, 2½ miles west-south-west of Bryneglwys; near Nant-Clywd, on the west of the Vale of Clwyd; and possibly on the eastern flank of the Clwydian range near Moel-yr-acre. The *scanicus* and *tumescens* zones occur west of the Vale of Clwyd. The *nilssoni* zone covers a large area between the Bala and Llanelidan Faults. The Dinas-Brân Beds have not been identified with certainty.

[1] See E. M. R. Wood (Shakespear), Q. J. G. S. vol. lvi (1900) p. 446.

(c) Intrusions in the Lower Ludlow Series.

An olivine-dolerite (tholeite) occurs as small dykes in a few places in the Lower Ludlow rocks. Mr. Lake mentions one near Pen-y-vivod. Another outcrop is in the Afon-Ro, about 200 yards from its confluence with the Dee; but there is no proof that the two form parts of the same dyke. Although the rocks have not been found *in situ*, there is evidence of a third occurrence on Craig-y-Rhos, a hill half a mile north of Glyn-Dyfrdwy.

(4) ? Upper Ludlow Series.

Dinas-Brân Group.—The rocks forming the conspicuous hill, crowned with the remains of the ancient fastness of Castell-Dinas-Brân, have long been regarded as the highest Silurian in the area. They are uncleaved, thinly-bedded, slightly calcareous, sandy shales, usually micaceous, and occasionally fossiliferous.

Mr. Lake (Q. J. G. S. vol. li, 1895, p. 20) gives a list of fossils from here, several of which have been also collected during the present survey. The following new records may be added:—

Chonetes cf. *striatella* Dalman.
Orthis cf. *lunata* J. de C. Sowerby.
Orthis cf. *orbicularis* J. de C. Sowerby.
Orthonota cf. *amygdalina* J. de C. Sowerby.
Pleurotomaria sp.
Orthoceras ludense J. de C. Sowerby.

Dayia navicula is the commonest fossil here, and has also been found at various other localities nearer Llangollen. Mr. Lake suggested that the fauna indicated an Upper Ludlow age. Since then Miss G. L. Elles & Miss I. L. Slater[1] have described in detail the Ludlow Series at Ludlow, giving an extensive list of fossils. According to these authors, *Dayia navicula* is not found in the Upper Ludlow. Its abundance in the Dinas-Brân Group suggests a correlation of that with the Mocktree or *Dayia* Shales; but, as these fall in the zone of *M. leintwardinensis*, which at Llangollen is known to underlie the Dinas-Brân Beds, and as, with this exception, the fossils are, generally speaking, common to both Lower and Upper Series, we are inclined to agree with Mr. Lake in assigning the group to the Upper Ludlow.

IV. Structures.

In the succeeding portion of this paper, we attempt to describe the structures that have resulted, in the main, from mountain-building movements in Devonian times, although in part from a continuation of the cycle of movements into later ages. But the later movements have merely modified, and not obliterated, the major tectonic features that were rough-hewn by the Caledonian folding.

[1] 'The Highest Silurian Rocks of the Ludlow District' Q. J. G. S. vol. lxii (1906) pp. 195–222.

The Lower Palæozoic rocks are folded on approximately east-and-west axes into a series of major and minor synclines and anticlines, which are cut through by a few mighty master-faults and a multitude of smaller adjustment-faults. The earth-stresses were so intense that all save the most resistant rocks were severely cleaved.

Practically all the folding was effected in Devonian or early Carboniferous times, while the major faults were also initiated then. Proof of these statements can be seen in the transgressive unconformity of the *Dibunophyllum* Zone of the Carboniferous Limestone, which strikes north and south at right angles to the earlier structures. All the Carboniferous is subject, on the one hand, to wide gentle warping that did not modify to any appreciable degree the Devonian folds below; and, on the other hand, to influential faulting that produced considerable displacement of the fault-blocks already defined by the earlier movements.

The problems of the tectonics of the region fall, therefore, naturally under two headings, namely:—(*a*) Pre-Carboniferous, (*b*) Post-Carboniferous. This is true only in a general way, however; for the earth-movements went on intermittently throughout the Devonian, Carboniferous, Permian, and Triassic Periods, and possibly in even more recent times. In a paper dealing with the Lower Palæozoic rocks, a full account of the Devonian movements is appropriate and will be attempted here; while the post-Carboniferous modifications can only be touched upon.

In the following description of the structures, our views have in part been influenced by the fact that one of us (B. S.) has collaborated with Mr. C. B. Wedd, of H.M. Geological Survey, in a study of the tectonics of North Wales. This study has led us to regard the structure of the Llangollen district as produced by torsion, set up by stresses originating in the Caledonian movements of Devonian times and continuing to act in later epochs. In this paper the data are set forth, without emphasizing their bearing on the torsional hypothesis.

Pre-Carboniferous Movements.

Viewed in the broadest outline, the area is embraced by the following essentially pre-Carboniferous structures (fig. 1, p. 178):—

Clwydian Anticline—the north-eastward extension of the Harlech Dome.
Llanelidan Syncline—expressed by the Llanelidan Fault.
Mynydd-Cricor Nodal[1] Anticline.
Bryneglwys Synclinorium.
The Central Wales or Llandderfel Syncline.
Bryneglwys Fault.
Cyrn-y-Brain Nodal Anticline.
Llangollen Synclinorium with the Corwen Buttress.

[1] The anticlines defined as nodal bring to the surface Ordovician rocks, which, by their superior toughness, appear to have acted as knots, or nodal points, in the general earth-movement (see p. 212).

Clwydian Anticline.—At the present time, the graben of the Vale of Clwyd, with its stupendous eastern boundary-fault, makes it difficult to appreciate the pre-Carboniferous structure. However, the Lower Ludlow rocks of the Clwydian range and of the country on the west of the Vale appear to form part of the extension north-eastwards of the great Harlech Dome. The axis of the anticline probably strikes east and west in this region, and appears to lie somewhere in the latitude of Moel-Famau, where Wenlock Beds are found.

Although the initiation of the depression of the Vale of Clwyd probably took place in pre-Carboniferous times, it did not obliterate the effects of the folding. The rocks on each side of the Vale appear to have formed part of a local dome on the axis of the great Harlech upfold: for in the Nant-Clwyd area, west of the Vale, the folds pitch westwards, whereas in the Clwydian range they pitch eastwards. Further, in conformity with this general doming, we find in the Nant-Clwyd area that the *leintwardinensis*-beds cover most of the ground, while they also probably occupy the easternmost part of the southern end of the Clwydian range.

Llanelidan-Fault Syncline.—In view of the facts just related, it is held that in pre-Carboniferous times a synclinal tendency existed between the Clwydian anticline and the dome of Mynydd-Cricor. This tendency found its expression chiefly in the Llanelidan Fault, which strikes almost due east and west between the present trough of the Vale of Clwyd and the surviving half of the Cricor dome, and ultimately passes between the Millstone Grit of Moel-Garegog and the Ordovician of Cyrn-y-Brain. Considerable movement has taken place in post-Carboniferous ages along this fault; but it was one of the great master-faults in this region in Devonian times. The displacement produced by it has probably always been lateral rather than vertical, the block of country south of it travelling eastwards relative to that on the north. At the same time, it is probable that it conformed to the synclinal tendency by a downthrow northwards: for north of the Llanelidan Fault the Carboniferous Limestone rests upon the higher part of the Lower Ludlow, while, south of that fault, on Cyrn-y-Brain it lies upon Ordovician. It must also be pointed out that the Limestone crosses the Cyrn-y-Brain anticline by transgressive overlap, much of the lower part being absent. The post-Carboniferous movement along the Llanelidan Fault is, therefore, less than is suggested by the displacement of the outcrops (from a point immediately west of Minera to a mile and a half south-west of Llandegla).

Mynydd-Cricor Nodal Anticline.—In the area between the Llanelidan and the Bryneglwys Faults the dominant structural feature is the periclinal dome of Mynydd-Cricor, the northern half of which is cut off by the Llanelidan Fault.

The core of Ordovician slates and grits of Mynydd-Cricor is

followed on the east and south by a broad stretch of Valentian Slates, dipping outwards, and broken by numerous faults.

On the south the dip is mainly southwards, but traced eastwards the strike swings round through north-east to north until it is almost north-north-west near the Llanelidan Fault. The change in strike suggests the dragging-round of the beds by the westward displacement of the block of country north of the Llanelidan Fault.

The numerous faults affecting the area appear to be adjustment-faults ancillary to this anti-clockwise twist. They slice across the dome with strikes varying from almost north-west in the east to north in the west. They throw down sometimes one way, sometimes the other. At the western end of the dome the arrangement of the strata is more complicated. A triangular strip of country is found there having the dip inwards towards the dome, from which it is separated by a fault. As a result of this arrangement the Wenlock is brought to lie against Ordovician a quarter of a mile west of Cricor Farm; while farther south, the Tarannon and the Wenlock Series are in juxtaposition.

The rocks in this strip of country are affected on its south side by two curved thrust-faults, convex towards the south and south-west. The more southerly thrust forces Pen-y-glog Grit over the Ludlow Series; while the second, which may be termed the Ffynnon-Tudur Thrust, carries Lower and Upper Valentian over the Grit.

Bryneglwys Synclinorium.—The general anticlinal structure of the Cricor dome gradually merges southwards into a complex synclinorium, the axis of which runs east and west in the neighbourhood of Moel-Truan, 2 miles west by south of Bryneglwys. The structure hereabouts is similar to that of the northern half of the Llangollen Synclinorium (see p. 213), and the two regions occupy analogous positions with regard to the Mynydd-Cricor and Cyrn-y-Brain domes respectively. The similarity of structure suggests that the two synclinoria are parts of one structure, subsequently displaced laterally by the Bryneglwys Fault.

Cyrn-y-Brain Nodal Anticline.—The great anticlinal dome of Cyrn-y-Brain constitutes a node of Ordovician rocks similar to, though larger than, that of Mynydd-Cricor. Both nodes have similar effects on the rocks to the south of them.

Cyrn-y-Brain mountain is covered to such an extent by peat and heather, except around its periphery, that little can be made of its internal structure; but on its northern side there are patches of Valentian involved in the faulting, which show that, as a whole, the rocks are arranged as a periclinal dome. The large area covered by the Ashgillian Beds makes it almost certain that the anticline is complex in structure. The western end of the dome has been faulted out of sight by the Bryneglwys Fault or fault-

plexus which joins the Llanelidan Fault at Llandegla (see map, fig. 5, p. 220). The faulting has locally produced considerable shearing, the rocks being almost converted into mica-schists.

A broad outcrop of Lower Valentian rocks occurs on the southern side of Cyrn-y-Brain in which the rocks have fairly-uniform southward dips; but the structure may not be so simple as it seems, for strike-faulting may be easily overlooked in so monotonous a series. We know, in fact, that near Plas-uchaf the World's-End Fault cuts out a large part of the Lower Valentian in the eastern part of its course, and passing westwards it eliminates much of the Tarannon Series.

The Tarannon outcrop belongs more naturally to the complex northern half of the Llangollen Synclinorium, and will be dealt with under that head (see p. 213). It may be suggested, therefore, that the core of Ordovician and Lower Valentian rocks acted as the head of a ram that was thrust into the syncline of newer strata, and produced the concertina-folding in them.

As in the case of Mynydd-Cricor, so on Cyrn-y-Brain, a number of transverse adjustment-faults (probably partaking of the nature of tear-faults) comply with the demands of torsional movement. These faults have little effect on the tough Ordovician greywackes, but become more conspicuous in the Valentian. Their general direction is usually more or less north and south.

Llangollen Synclinorium (see Pls. IV & V).—This structural element may be defined as embracing the broad outcrop of Upper Silurian rocks southwards from Cyrn-y-Brain, across the Dee Valley, to the northern flank of the Berwyn anticline with its north-western buttress that projects towards Corwen. The synclinorium is obliquely truncated on its north-western side by the Bryneglwys Fault.

The synclinorium as a whole pitches eastwards, and its axis strikes between 10° and 20° south of east roughly along the line of the Dee Valley.[1] North of this lies a complex limb in which concertina-folding has taken place, the axes of the minor folds having the same strike as that of the whole synclinorium. South of the axial line the structure is extremely simple, the rocks being gently folded into a single, shallow, pitching fold. The average angle of the pitch varies between 5° and 10° (Pl. IV).

The two structural units contrasted in the last paragraph merge in reality more or less one into the other in the axial region; but a convenient boundary may be found in the Llangollen Fault,

[1] The structure will be more readily understood if reference be made to the map (Pl. V) and serial sections (Pl. IV). It must be pointed out again that, owing to the absence of easily traceable horizons in the monotonous Denbighshire Series, and to the complexity of the structure, both map and sections are to some extent generalized. The generalization is, however, based upon an enormous number of observations made during the re-survey of the area. Even so, the boundaries of the subdivisions suggest a degree of certainty that is unjustifiable.

which, with a large downthrow northwards, strikes east 10° south roughly parallel to the axis. Throughout the synclinorium the cleavage has a general strike of east 10° to 20° south.

Before we enter upon the details of the folding, it will be well to describe the major faults.

Parallel to the Llangollen Fault and about 2 miles south of it, runs another master-fault, the Glyn-Ceiriog Fault, which also throws down northwards. The parallelism of these two faults with the direction of folding and cleavage emphasizes their connexion with the stresses that caused both. It is thought that in both cases the initiation of the fault may have been connected with the bending-down of the Llangollen Basin, and that possibly they may be in the nature of 'undertow faults.' But, at any rate in the Llangollen Fault, such movement appears to have been accompanied and succeeded by lateral movement westwards of the block on the northern side of the fault.

This movement appears to have induced a series of adjustment-faults with a general northwestward trend springing from the master-faults. In some of these an apparent eastward downthrow may in reality represent a northward lateral displacement of the block on the east of the fault. Other of the adjustment-faults counteract the effect of the pitch of the synclinorium by throwing up eastwards, thus allowing its great length to be compatible with a steep pitch throughout.

Of the adjustment-faults springing from the Llangollen Fault, the most important are the Aqueduct Fault (separating Carboniferous from Silurian north-east and north of Llangollen), the Llandynan Fault, and the Rhagatt-Hall Fault; while the following are connected with the Glyn-Ceiriog Fault:—The Castle-Mills (near Chirk Castle), the Pont-fadog, the Nant-Fridd-isel (near Carrog), and the Bonwm (near Corwen) Faults, as well as a number of less conspicuous ones (see fig. 1 & Pl. V).

The complex folding of the northern limb of the synclinorium may now be dealt with in somewhat greater detail. Abandoning the consistently southward dips observed on the flanks of Cyrn-y-Brain, the rocks, from the Tarannon slates upwards, become involved in a type of structure best described as 'concertina-folding' (see sections, Pl. IV).

Upfold and downfold follow each other in rapid succession, with their axial planes nearly vertical and sometimes reversed. The packing of the folds has gone so far in places that an isoclinal structure has been produced. The height of the folds does not seem to be great, and sometimes the bottom of one fold and sometimes the top of another are found at the surface, dissected for us by the deep valleys.

As the axial area of the synclinorium is approached, flatter dips become the rule, although in places sharp buckling disturbs the gentler folds. This is well seen near the gorge of the Dee at

Berwyn, on a large scale; while a miniature reproduction of the sharp buckle superimposed on a gently pitching fold may be studied on a few square yards of rock laid bare in the bed of the Dee when the river is low, at a point a quarter of a mile below the 'Chain Bridge.'

It is natural to expect a considerable amount of faulting and thrusting to accompany this concertina-folding; but, although there is doubtless far more strike-faulting than has been discovered, it is probable that the materials were extremely plastic at the time of the movement. In some cases it may be seen in quarry-sections that the beds can pass from a horizontal into a vertical position within a few yards by folding.[1] Yet we feel that the sections in Pl. IV would more nearly conform to the truth if they showed more faulting in the steep limbs of the folds. The faults that are shown were either observed in the field, or else were inferred with considerable certainty from a study of the strata mapped.

A small area round Moel-y-faen may be chosen to illustrate the structure of the whole northern limb of the synclinorium. The map (Pl. III) shows that the surface-expression of the concertina-folding is, at first sight, puzzling in the field, owing to the singularly rapid changes in the amount and direction of dip that is observable. But, when carefully studied, the variability resolves itself thus:—Belts of country varying in width from 100 yards to about half-a-mile, and often with nearly parallel boundaries, run across country in a direction 10° to 20° south of east. In alternative belts very steep dips (stippled on the map) and very gentle dips (plain) are found. Within the belts of steep dip the strike is consistently east and west, while in the belts of low dip the strike varies, but the dip usually has an easterly component. The former represent the steep flanks of the tightly-packed and sometimes isoclinal folds and overfolds, the latter their crests and troughs. In the belts of low dip, the easterly component is imparted by the pitch (partly original and partly due to a general tilt of the whole region that finds expression in the eastward dip of the Carboniferous). In the steep flanks of the folds this eastward pitch is masked, although it accounts for the difference between the strike of the individual beds (east and west) and the run of the belt of high dip (east 10° to 20° south).

It is perhaps unnecessary to describe in detail the map (Pl. III). It should be read in conjunction with the sections in Pl. IV (3rd, 4th, & 5th from the top). Nor is it proposed to describe the rest of the complex limb of the Llangollen Synclinorium, which is sufficiently illustrated by Pls. IV & V, with the

[1] The plasticity of the rocks as a whole has found expression in a variety of minor structures, such as slickensides and grooving along the bedding-planes, movement-surfaces between cleaved shale and almost uncleaved silty sandstone, internal contortion of sandstone-bands, the drawing-out of sandstone-bands into sausage-like lenticles, etc.

exception of the Caer-Drewyn area in the angle between the Bryneglwys and Llangollen Faults.

Caer-Drewyn Hill forms part of an area shaped like an isosceles triangle, lying between the converging Bryneglwys and Llangollen Faults which form its two long sides, and the Rhagatt-Hall Fault, which forms its base (fig. 4, p. 216). It occupies a position analogous to that of the patch of Tarannon shale lying between the converging Llanelidan and Bryneglwys Faults, south-east of Llandegla (p. 219); but, owing to the different rocks and movements involved, the resulting structure is somewhat different.

The rocks in the apex of the triangle and along the southern (or Llangollen Fault) side are concealed by drift and alluvium, the exposed rocks consisting of Valentian Slates and Pen-y-glog Slates and Grits. It seems probable that the rocks thrown down by the Bryneglwys Fault on its northern side also had a horizontal movement south-westwards; while those south of the Llangollen Fault (also throwing down north) travelled eastwards. The stresses involved squeezed the rocks in the triangle, and set up a movement of revolution in an anti-clockwise direction. The resistance of the tough Wenlock grits to the pressure apparently caused them to buckle into a syncline, and finally to break and to be overridden, except along the base of the triangle, by the underlying shales. The boundary between the grit and the shales is everywhere shown by the mapping to be a fault.[1]

Simultaneously with the squeeze came the attempt at revolution which caused the rocks to fracture by transverse faults. The thrusting appears to have taken place to a greater or smaller degree in the strips between these faults, at some points bringing the Lower Wenlock Shales, at others different horizons of the Tarannon Shales, against the Grits.

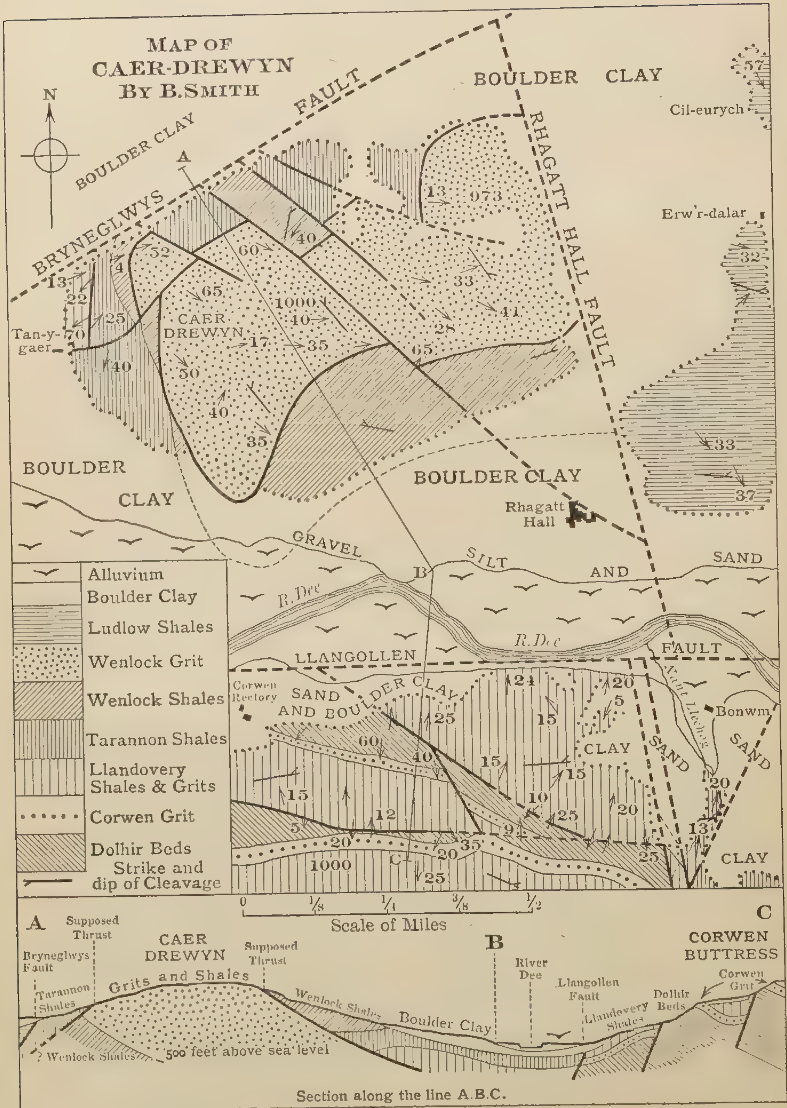
South of the Llangollen Fault, the adjustment-faults and the simple pitching synclinal structure have already been noted; but the western termination of the fold is also of interest, and may now be described.

Corwen Buttress.—The syncline passes westwards into a projection of the Berwyn anticlinorium that may be appropriately termed the Corwen Buttress. It occupies the high ground west of the Bonwm Fault and south-east of the Bryneglwys Fault, while the Llangollen Fault forms a convenient northern limit. It is an anticlinal spur separating the Central Wales (Llandderfel) Syncline from the Llangollen Synclinorium.

The whole of the ground has not been thoroughly examined; but it appears probable that it is occupied by shallow rippling folds which give a very broad outcrop to the Ashgillian and Lower Valentian beds that form it. The outcrop of the Corwen Grit on

[1] The interpretation of this fault as a thrust furnishes the only reasonable explanation of the geological map.

Fig. 4.



Section along the line A.B.C.

the map (Pl. V) brings out this rippling structure which, as it approaches the Dee Valley, becomes very much complicated by faulting (fig. 4), as was shown many years ago by Dr. Groom & Mr. Lake.[1] Of the faults, the east-and-west faults are now seen to be parallel to the Llangollen Fault and probably part of it, while the others may be grouped with the north-west or north-and-south adjustment-faults.[2]

The buttress doubtless operated to some extent as a resistant mass, comparable in its effects to the Cricor and Cyrn-y-Brain domes, and like them it has been truncated by the master-faults where it merges into the adjoining synclinal structures.

Berwyn Nodal Anticline.—The northern fringe only of the Berwyn Anticline falls within the scope of this paper. The region to be described may be said to be introduced by the Glyn-Ceiriog Fault to which reference has already been made (p. 213). The fault throws down northwards, and may also represent a westward movement on its north side; but its exact position and amount of displacement is not determinable with certainty. In the Moel-Fferna region it can be fixed fairly closely by reference to the easily recognizable grits and pale slates; but it is rather inferred than proved between the Moel-Fferna Slate-Mine and Glyn-Ceiriog, although from place to place signs of faulting have been noted. In the Glyn district it may have been touched in the Wynne Slate-Quarries, and its course down the valley to Llwyn-mawr is obviously implied by the abrupt termination of the Pen-y-glog Slates, the Valentian, and the Glyn Grit, on the south side, and the introduction of the Glyn-Dyfrdwy stage on the north side of the valley. This was not appreciated by Dr. Groom and Mr. Lake, and appears to nullify some of their arguments for the movements postulated for the Cae-mor Fault.[3]

Near Dol-y-wern the Glyn-Ceiriog Fault probably divides into three branches, the westernmost of which is the Cae-mor Fault of Groom & Lake. It is not certain by any means which of the three lines forms the true continuation of the Glyn-Ceiriog Fault towards the south-east. If it be the Cae-mor, there is an abrupt change in strike of the fault; and it is more likely that the middle branch which runs into the greatly disturbed region west of Craignant was in pre-Carboniferous times the most important structural fault. On the other hand, the northernmost branch swings round into a fault-line of great importance in post-Carboniferous times, which passes across the coalfield at Chirk. The ground east and south-east of Dol-y-wern is complex, and obscured by Glacial drift. No attempt at finality can be claimed in the solution of the faulting hereabouts, and therefore we do not

[1] Q. J. G. S. vol. xlix (1893) pp. 426–39.

[2] The part of the map (fig. 4) neighbouring Corwen incorporates that of Groom & Lake with modifications in mapping by the present authors.

[3] Q. J. G. S. vol. lxiv (1908) pp. 585–87. They spell it 'Cae-mawr.'

propose to criticize or discuss the nature of the Cae-mor Fault as described by Dr. Groom & Mr. Lake, beyond claiming that it does not pass northwards of Llwyn-mawr, for the mapping of the rocks on the valley-sides north of Dol-y-wern precludes the possibility of this.

South of the Glyn-Ceiriog Fault the same simple structure noted between it and the Llangollen Fault persists. The gentle northward dip steepens somewhat, it is true, and a greater number of adjustment-faults can be proved in the older rocks, which are possessed of more distinguishing qualities than is the Lower Ludlow Series. The faults range from almost north-and-south in the west to north-west and even west-north-west in the east.

The simplicity of the structure appears to be disturbed in the eastern part of the area by the Dolhir strike-fault at the base of the Ashgillian. This fault has already been discussed on p. 189. It may be noted, however, that it has the same general strike as the Llangollen and Glyn-Ceiriog Faults, and is a thrust.

Probably other strike-faults occur in this area, but none of any magnitude have been definitely proved. The thinness of the Valentian at the outcrop near Glyn-Ceiriog perhaps may be due to such a fault (p. 199).

Caledonoid Structures.

All the structures so far considered are related to folding on almost east-and-west axes. There are, however, two south-west and north-east ('Caledonoid,' as the late Prof. Charles Lapworth would have called them) features of prime importance to the district.

(*a*) Central Wales or Llandderfel Syncline.—The first may be called the 'Llandderfel,' or, better, the 'Central Wales Syncline,' for it is a continuation of the downfold to which Prof. O. T. Jones[1] gave the latter name farther south. The syncline lies for the most part outside the area under description. The Dee Valley follows it from Llandderfel to Corwen. Its influence is seen in the westward pitch of the western end of the Berwyn Dome. The downfold cannot be definitely traced north-east of Corwen. Two explanations of its disappearance seem possible: either the fold has been bent on the fulcrum of the Corwen Buttress into an east-and-west structure (the Llangollen Synclinorium); or the synclinal tendency has found expression in the westward downthrow of the Bryneglwys Fault between Corwen and Llandegla, and in the synclinal arrangement of the strata between Mynydd-Cricor and Cyrn-y-Brain (pp. 219, 220).

(*b*) Bryneglwys Fault.—The second great 'Caledonoid'

[1] 'The Geological Structure of Central Wales & the Adjoining Regions' Q. J. G. S. vol. lxviii (1912) pp. 328–44.

structure is the fault which ranges obliquely across the Central Wales Syncline from Llandderfel to Corwen, and thence (as shown in Pl. V) to Llandegla. The part lying within the district described in this paper has been named the Bryneglwys Fault, although, according to the Old Series maps, it is merely part of the great Bala Fault. Until this interpretation has been confirmed, a local name appears preferable. At Llandegla it joins the Llanelidan Fault, and the two pass as one across the northern side of Cyrn-y-Brain, and so into the Carboniferous country on the north-east.

The Bryneglwys Fault is in reality a plexus of subparallel fractures that enclose lenticular strips of various rocks. The nature of the fault can be best studied near Llandegla, and is illustrated in fig. 5 (p. 220). Here we find in the angle between the converging faults a triangular patch of Tarannon Shales. Probably the rocks north of the Llanelidan Fault moved westwards, and those south of the Bryneglwys Fault eastwards, relative to the block in between. The Tarannon Shales, squeezed between the two faults, have been tilted towards the Bryneglwys Fault, and thrust westwards over the lowest Wenlock zones, which either dip towards, or strike against, the junction. Farther west and southwest these Wenlock rocks form a (probably convex) syncline, the axis of which runs nearly due north and south, but is slightly curved so as to be convex westwards. Its axial plane is inclined eastwards. In the centre of the syncline Ludlow rocks crop out. This area seems to have been subjected to a clockwise movement which has twisted round the cleavage nearly 90° from the normal direction (see p. 221), so that it now strikes about due north and south and dips westwards.

The triangular patch of Tarannon Shales, which we have just shown to be bounded by a thrust on the west, is faulted on the north by the Llanelidan Fault against a wedge of high-zone Carboniferous Limestone, which itself is separated by a secondary fracture on its north side from the Cefn-y-fedw Sandstone, south of Llandegla.

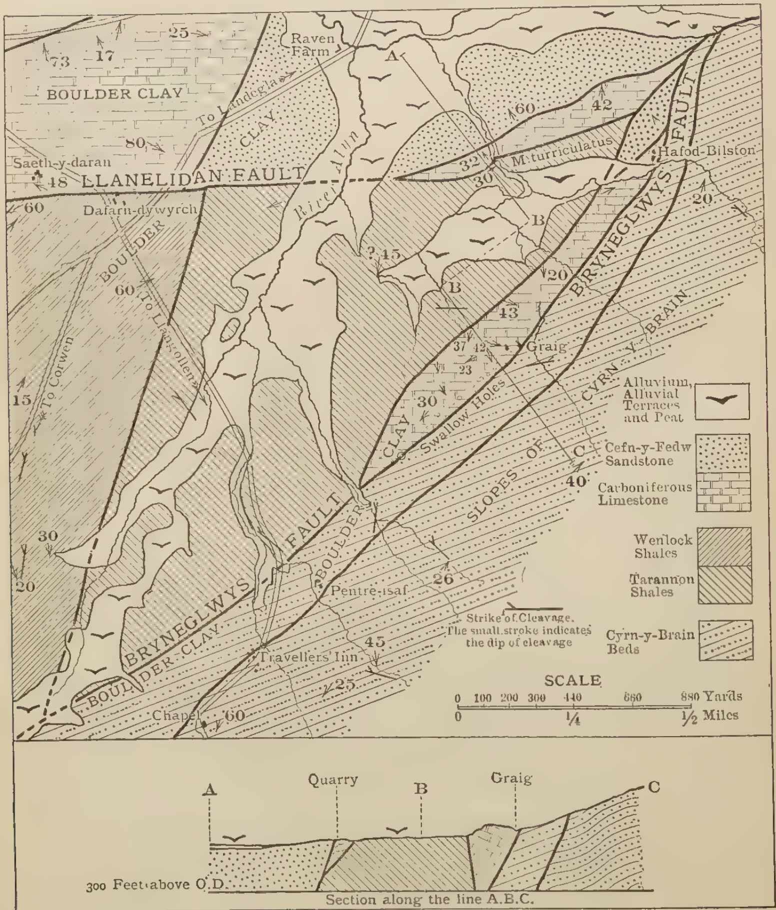
The multiple nature of the Bryneglwys Fault-fracture is well seen on the south-eastern side of the triangle of Tarannon Shales. Here we find strips of Middle or ‘White’ Limestone and of Cefn-y-fedw Cherts dropped down between the above-mentioned Tarannon and the Ashgillian of Cyrn-y-Brain. The main branch of the Bryneglwys Fault between the Limestone at Craig and the Ashgillian is concealed by Boulder Clay, though indicated by a fine series of swallow-holes.

The south-easternmost branch of the Bryneglwys Fault can be traced subparallel to the main fault across the north-western flank of Cyrn-y-Brain. It cuts off a corner south-east of Llandegla, and produces the shatter-belt along which the Hafod-dafalog stream has excavated its deep valley.

For long distances south-westwards the line of the Bryneglwys Fault is masked by Glacial drift that obscures the flat-bottomed hollow in which it lies.

Speaking generally, the apparent aggregate throw of the fault-plexus is down to the north-west. Thus it truncates the Corwen Buttress, bringing Silurian and Carboniferous against the Ordovician; it cuts across the Llangollen Synclinorium so that *leintwardinensis* beds which only crop out in the heart of the basin

Fig. 5.



near Llangollen, reappear in the Bryneglwys area. Again, it shears across the western and northern sides of the Cyrn-y-Brain Dome, in such wise that Valentian and Carboniferous rocks lie against the Ordovician. In the Carboniferous it produces a great displacement westwards on its northern side.

The exact nature of the movement which produced these apparent displacements is not quite clear. Where the Bryneglwys and Llanelidan Faults become one, there seems evidence of a southward crushing from the north, producing a sort of thrust, but not necessarily an overthrust; for, concurrently with this, there was relative movement of the block of country south of the fault in an eastward direction. A similar lateral movement doubtless occurred along the Bryneglwys Fault south-west of Llandegla.

Despite its Caledonian trend, the Bryneglwys Fault owes its conspicuous displacement to post-Carboniferous movements; and it is by no means easy to decide the function which it played in the Devonian dislocations. There is no doubt, however, that it was even then one of the master-faults of the region.

Cleavage.

The Devonian movements subjected all the Lower Palæozoic rocks of this district to forces that produced cleavage in them, in greater or less degree according to their nature and their position in relation to the folds.

Over the greater part of the area, there is a marked agreement in the strike of the cleavage with the strike of the folds and buckling, so that a direction between east 10° and 20° south is normal. The dip is northwards and, except south of the Llangollen Fault where it is consistently about 30°, it may be said elsewhere to average 60° to 70°, although occasionally it is as low as 30° or as high as 85°. The northward dip suggests that the cleavage-forces (and therefore also the forces producing the folding) acted from north to south. The movement was, in our opinion, a superficial southward displacement relative to a more powerful and deeper-seated northward or northwestward Caledonian movement in areas not far removed from, or even underlying, this tract of country. The presence of a thorough, though low-dipping cleavage in the very gently folded rocks south of the Llangollen Fault and on the flanks of the Berwyn Anticline may, perhaps, be cited in favour of such an origin for the cleavage-forces. Be this as it may, the occurrence of good roofing-slates in beds in which the true dip is 10° to 15° and the cleavage-dip about 30°, both northwards, is remarkable and difficult to explain. Yet these conditions hold throughout the outcrop of the Pen-y-glog Slates from Carrog to Glyn-Ceiriog.

Post-cleavage faulting has upset the general direction of cleavage-strike and dip in a pronounced manner in the area between the Llanelidan and Bryneglwys Faults, eastwards from Llanelidan and Bryneglwys; in many cases the strike has been rotated from east-and-west to about north-and-south, so that the dip is now westwards. In such cases the true dip and strike of the folded rocks have undergone a similar alteration, and it is obvious that the whole block defined by the faults has rotated, probably in post-Carboniferous times. This is well illustrated in fig. 5.

The cleavage movements have produced a variety of minor structures of interest, which space forbids us to describe here. It may, however, be pointed out that these structures usually occur where hard and soft bands are interbedded. It is characteristic of this district that the effect of the pressure has usually been to break up the harder bands into phacoidal fragments, rather than to produce contortions of these bands as a whole. It is by the shuffling of the phacoidal fragments that the necessary adjustment appears to have been brought about.

V. The Pre-Carboniferous Floor.

The folding, faulting, and cleavage so far described formed part of the Devonian mountain-building. Vigorous erosion accompanied and followed the elevation, and eventually produced a peneplain. But we can still see in the form of the floor upon which the Carboniferous rests, the influence of the major tectonic features on the then-surface relief; for the anticlinal areas tended to stand out as hills, and the synclinal areas as depressions. On the line of the Llangollen Synclinorium the red Basement Beds occur, followed by the maximum thickness of Carboniferous Limestone, suggesting that here was a bay opening eastwards. The successive overlap of higher and higher beds against the anticlinal area of Cyrn-y-Brain can be clearly seen on the north (see p. 210), while southwards towards the Berwyn Dome the thinning of the Limestone is even more rapid. The steeper submarine contours on this side of the ancient bay may have been related to the Llangollen Fault.

It has already been pointed out, in passing, that much of the movement along the Llanelidan Fault took place in pre-Carboniferous times. This may be argued from the fact that the Limestone lapping round the northern slope of the Cyrn-y-Brain and Cricor Domes transgresses rapidly from the Ordovician on to the higher part of the Lower Ludlow rocks.

In a similar way the assumption of movement along the Bryn-eglwys Fault in pre-Carboniferous times helps to explain the occurrence of the Carboniferous Limestone at Corwen. Were it not for this possibility, the amount of movement required to introduce it there, by faulting, would be stupendous.

VI. Post-Devonian Modifications.

The discussion of the post-Devonian changes is difficult, because most of the evidence lies beyond the limits of the Lower Palæozoic outcrops, in the tectonics of the newer rocks on the east.

All the post-Devonian movements appear to be explicable on the assumption of the continuous application of stresses, of varying intensity, which found expression in (*a*) widespread warping, influenced by the major folds in the older series; and (*b*) renewed movement along already-established fault-lines.

Although the folding or warping had little effect on the Lower Palæozoic substratum, the faulting that accompanied it produced

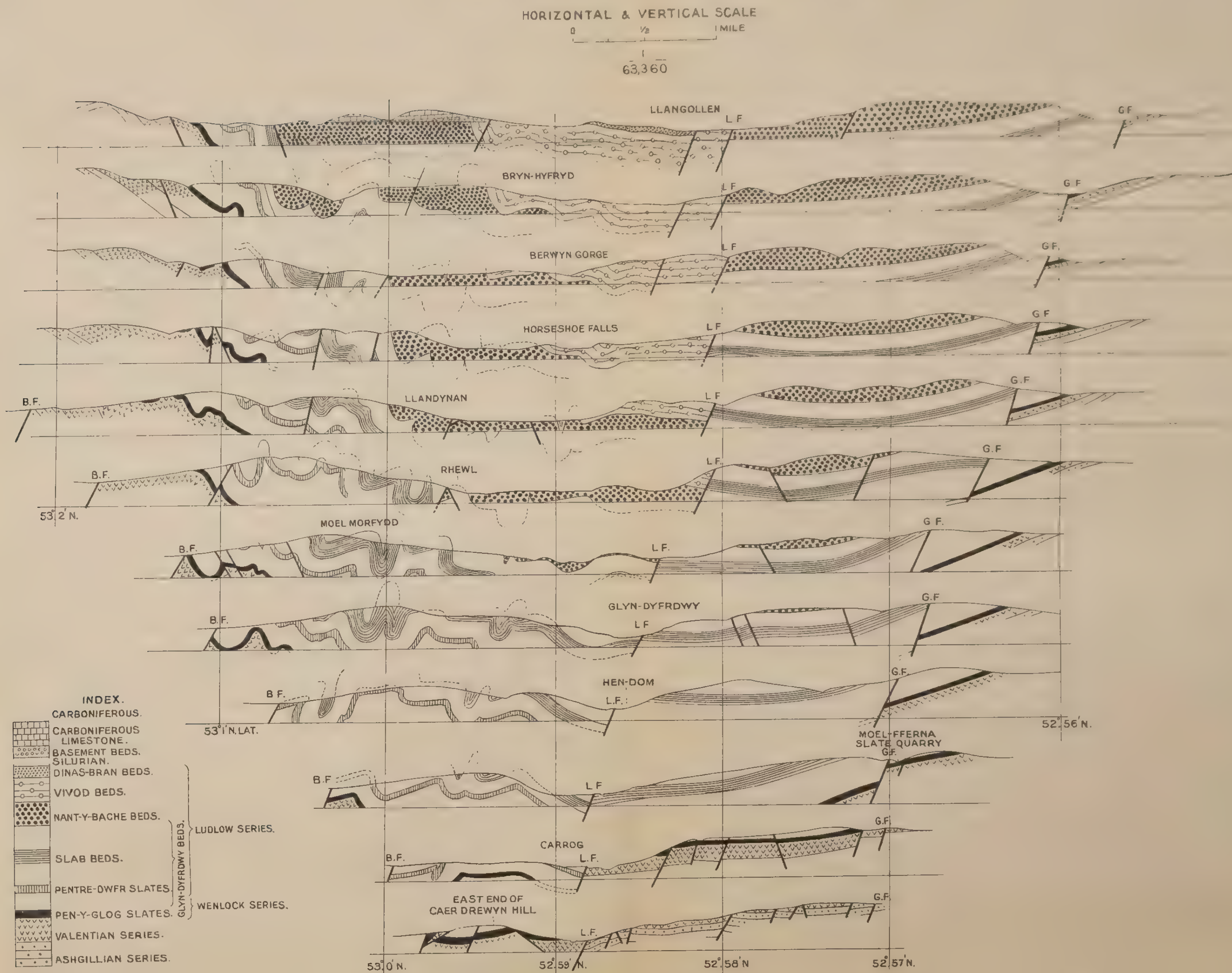
Map of the Area round Moel-y-faen, illustrating the Structure of the Northern Limb of the Llangollen Synclinorium.

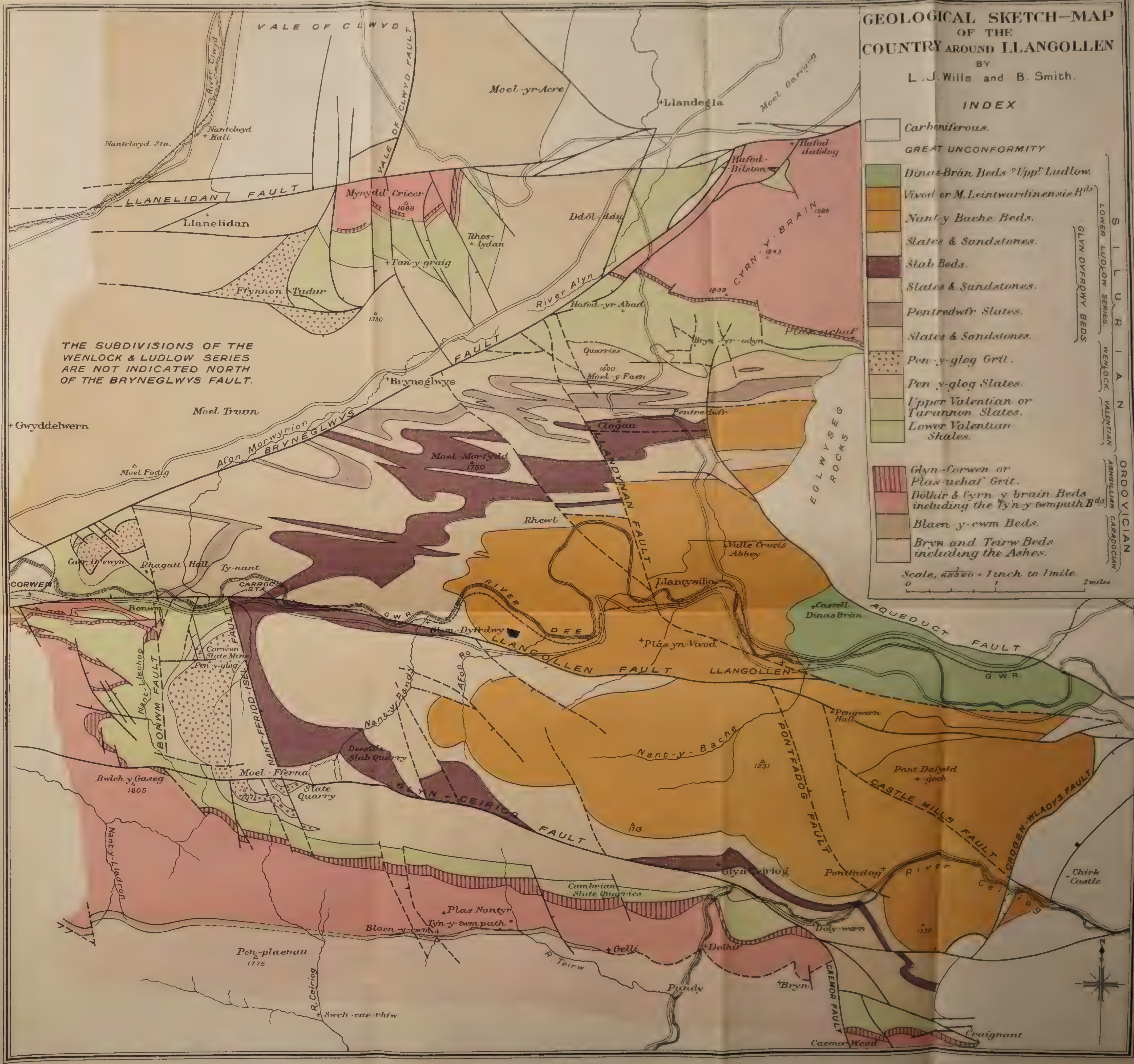
NORTH–SOUTH SERIAL SECTIONS ACROSS THE LLANGOLLEN SYNCLINORIUM

BY L. J. WILLS.

THE VERTICAL LINES ARE DRAWN AT EVERY MINUTE OF LATITUDE

B. F. BRYNEGLWYS, L. F. LLANGOLLEN, G. F. GLYN-CEIRIOG FAULTS.




GEOLOGICAL SKETCH-MAP OF THE COUNTRY AROUND LLANGOLLEN
BY L. J. Wills and B. Smith.
INDEX
Carboniferous.
GREAT UNCONFORMITY
Dinas-Brân Beds ? Uppr. Ludlow.
Vivod or M. Leintwardinensis Bds.
Nant-y Bache Beds.
Slates & Sandstones.
Slab Beds.
Slates & Sandstones.
Pentredwfr Slates.
Slates & Sandstones.
Pen-y-glog Grit.
Pen-y-glog Slates.
Upper Valentian or Tarannon Slates.
Lower Valentian Shales.
Glyn-Corwen or Plas-uchaf Grit.
Dôlhir & Cyrn-y brain Beds including the Ty'n-y-twmpath Bds.
Blaen-y-cwm Beds.
Bryn and Teirw Beds including the Ashes.
SILURIAN
LOWER LUDLOW SERIES.
GLYN-DYFRDWY BEDS
WENLOCK
VALENTIAN
ORDOVICIAN
ASHGILLIAN
CARADOCIAN
Scale, 1/63360 = 1 inch to 1 mile
0
1
2 miles
THE SUBDIVISIONS OF THE WENLOCK & LUDLOW SERIES ARE NOT INDICATED NORTH OF THE BRYNEGLWYS FAULT.
VALE OF CLWYD
VALE OF CLWYD FAULT
River Clwyd
Nantclwyd Sta.
Nantclwyd Hall
Moel-yr-Acre
Llandegla
Moel Garnog
Hafod-Bilston
Hafod dafolog
LLANELIDAN FAULT
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Mynydd Cricor
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Plas-uchaf
Quarries
1500
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1750
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CARROG STA.
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RIVER DEE
G.W.R.
Glyn-Dyfrdwy
Castell Dinas Brân
AQUEDUCT FAULT
LLANGOLLEN FAULT
Plâs-yn-Vivod
LLANGOLLEN
Corwen Slate Mine
Pen-y-glog
Nant-Llechog
BONWM FAULT
NANT-FFRIDD-ISEL FAULT
Nant-y-Pandy
Afon Ro
Deeside Slab Quarry
Nant-y-Bache
PONTFADOG FAULT
Pengwern Hall
Pant Dafydd-goch
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CASTLE MILLS FAULT
CROGEN-WLADYS FAULT
Moel-Fferna
Bwlch-y-Gaseg
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Slate Quarry
GLYN-CEIRIOG FAULT
1713
Glyn Ceiriog
Pontfadog
River Ceiriog
Chirk Castle
Nant-y-Lladron
Cambrian Slate Quarries
Plas Nantyr
Tyn-y-twmpath
Blaen-y-cwm
Doly-wern
1330
Pen-plaenau
1775
Gelli
Dolhir
R. Teirw
Pandy
Bryn
CAEMOR FAULT
R. Ceiriog
Swch-cae-rhiw
Craignant
Caemor Wood
N

great changes in its level, and by lateral movement, great changes in the relative position of the blocks of country into which it was already divided. These changes are to some extent self-evident from the map. Without going into the detailed structure of the Carboniferous, we can make the following statements:—

(1) All the master-faults (see Pl. V) moved again, and the fault-lines were propagated through the Carboniferous cover as major faults.
(2) The adjustment-faults which adjoin the Carboniferous can be shown to have moved, and by inference, therefore, all the adjustment-faults probably did so.
(3) Many of the adjustment-faults are curved, both in the older rocks (see Pl. V) and in the Carboniferous, and their peculiarities can be best explained by the assumption that they result from the torsion of the region.
(4) The down-sinking of the Vale-of-Clwyd graben along the Vale-of-Clwyd and Llanelidan Faults shows how a major synclinal tendency was expressed at this time by faulting rather than by folding.

EXPLANATION OF PLATES III–V.

Plate III.

Map of area round Moel-y-faen, illustrating the structure of the northern limb of the Llangollen Synclinorium (see p. 214), on the approximate scale of 1 inch to 666 yards, or 1 : 24,000.

Plate IV.

North-to-south serial sections across the Llangollen Synclinorium, on the scale of 1 inch to the mile, or 1 : 63,360. (See pp. 212, 214.)

Plate V.

Geological sketch-map of the country around Llangollen, on the scale of 1 inch to the mile, or 1 : 63,360. [The distinctive colour-bars have been accidentally omitted from the narrow strip of Corwen Grit, south of Bonwm.]

Discussion.

The Secretary read the following letter received from Mr. Bernard Smith:—

'It should be pointed out that Dr. Wills had actually commenced to map the Ordovician and Valentian rocks of Cyrn-y-Brain, in his spare time, before it was decided to map the ground officially. He was therefore forestalled by the Geological Survey; and it was my fortune to have allotted to me certain areas that he had planned to examine himself. Hence the collaboration that has given rise to this paper. The area covered by the latter, however, is much greater than Dr. Wills had contemplated mapping by himself, and the combined experience of two, if not three, surveyors—gained not only in this area, but in a more extensive field upon three sides of it—has been utilized.

'The structures now described may be taken as typical of what has happened in the district: they are, however, but a portion of a more widespread system in which a large part of North Wales is involved. It had been hoped that another paper written by Mr. C. B. Wedd and myself, would have been ready for communication to the Society at about this date, but that

paper has not yet been completely written. In it an attempt is made to co-ordinate the earth-movements and to explain their relations one to the other, both in place and in time. The present paper describes the results of some of these movements; the future paper casts its net wider, and also attempts to give reasons for the movements. Those movements that are mentioned in Dr. Wills's and my paper can be more clearly demonstrated in the larger area examined.

'If there is one point that requires emphasis at this stage it is this—that the cleavage-planes induced by the Caledonian directional movements, in the ground least disturbed by later faulting and torsional movement, dip invariably northwards. This points to a relatively greater northward movement in depth than at the surface.'

Mr. C. B. Wedd congratulated the Authors, with whom he had himself long been associated in North Wales, on their success in unravelling a complex and difficult piece of stratigraphy, and in producing a very fine map. Dr. Wills had referred to certain joint work on the tectonic structure of a larger district, by his colleague Mr. B. Smith and the present speaker, who regretted that that work was not yet ready for presentation to the Society.

The Authors had been handicapped in their account of the structure of the district by reluctance to use unpublished facts, of which they had knowledge, in regard to neighbouring ground outside their area. For example, the Minera fault-belt was essential to an understanding of the movements that had affected the Llangollen basin. That fault-belt, lying a little farther east, was a crescentic dislocation, extending with eastward convexity of curve from the combined Llanelidan and Bryneglwys Fault in the north to the Llangollen Fault in the south. It showed how the Llangollen Syncline, with the adjacent anticline north of it, had been torn away from the eastern tract and slewed southwards by a rotary movement to which the Authors had alluded. That fault-belt, proved by mining in the southern part of its course, where such a movement should afford relief from pressure, consisted of a 'horst'-like arrangement of opposite throws, individually large, but with no appreciable net result in vertical displacement, the main movement having been chiefly in a horizontal direction.

The speaker had called Dr. Wills's attention to the significance of an apparent displacement of the trough of the Llangollen Syncline beneath the Carboniferous rocks by the agency of the Aqueduct Fault, as shown by that Author's elaborate sections across the valley.

Prof. O. T. Jones congratulated the Authors on the completion of an admirable piece of stratigraphical work in a region of great difficulty. He enquired whether it was still believed that there is a break in the succession between the Caradocian and the Ashgillian; if not, he would be inclined to suggest, in view of the developments farther south, that the Blaen-y-cwm Beds will probably be found to belong to the *Dicellograptus-complanatus* Zone or to the *D.-anceps* Zone—in other words, to the Upper Hartfell Group.

The correlation of the shelly and graptolitic facies of the Bala was still far from satisfactory, and, in view of the undoubted

Ashgillian affinities of the fauna in the succeeding beds, the determination of the precise horizon of the shales would probably throw some light upon the relation of the Ashgillian to the Hartfell Group. A curious feature of the Upper Ashgillian fauna was the association of *Meristina crassa*, formerly regarded as a distinctive Lower Llandovery fossil, with undoubted Ordovician trilobites, such as *Chasmops*. In Britain such an association was apparently found only in this district, and it might help towards the comparison of the strata near the Ordovician-Silurian boundary in Wales and in Norway where Prof. Johan Kiær had united the *Meristina-crassa* Beds with the Ordovician.

The brachiopods of the Valentian to which Dr. Wills had referred were unfortunately very poorly preserved, and did not afford as much help in the subdivision of the series as one would like.

The structure of the region was extremely interesting, and was quite unusual for Wales. It seemed probable that the deviation of the folds from the usual north-east and south-west into the east-and-west direction was accounted for by the region being beyond the protective influence of the rigid masses of North Wales, and that the rocks had therefore been wrenched out of their usual direction. It was not, therefore, surprising that the Authors had found evidence of considerable torsional structures and lateral movement in the district.

The terms used in describing some of the structural elements appeared to have a theoretical implication which was not quite clear. Such were the 'nodal anticline' of Mynydd-Cricor and Cyrn-y-Brain and the 'Corwen anticlinal buttress.' He would like to know what was implied by the term 'nodal anticline' and what was its influence upon the structure. The expression 'buttress' appeared to imply that it had in some manner influenced the folding of the adjoining country; whereas it seemed clear that this anticline was the result of the same folding movement as that which affected the rest of the country, but that the stresses in the eastern region are different from those on the west.

Dr. T. T. Groom said that he had listened with great interest to Dr. Wills's lucid description of the Authors' work on the district. The structure, at any rate of the southern part of the area, with which alone he was familiar, while of much apparent simplicity, was in reality far from simple, and the Authors were to be congratulated on the achievement of a notable piece of work. The speaker was gratified by Dr. Wills's generous appreciation of his joint work with Mr. Lake, and by the close agreement with this of the Authors' independent researches. There seemed, indeed, to be few points of difference. He would like to ask the Authors whether they had been able to prove definitely the identity of the Glyn and Corwen Grits, which Mr. Lake and himself had left an open question; and to have fuller evidence of a continuity of deposition between the Ordovician and the Silurian deposits, since some of the facts seemed to be rather in favour of a break. With

regard to the Bala Series, he welcomed the introduction of a group of beds into the gap caused in the Ceiriog valley by the Dolhir Fault, which Mr. Lake and himself had only partly succeeded in filling. He lastly suggested the importance of recognizing phases in such movements as the Caledonian, and remarked that the evidence that had been given hardly sufficed to prove absolutely the 'Devonian' age of the earlier folding and faulting, and did not seem to take into consideration the possibility that important movements may have taken place in late Silurian or early Carboniferous times.

Dr. Wills, in replying, expressed his gratitude for the kind way in which the Fellows present had received the paper—gratitude in which he knew Mr. Smith would join. Many points had been raised in the discussion, and he could only attempt to answer some of them. Miss Elles's determination of the graptolites from the Blaen-y-Cwm Beds—which were very distorted—suggested a zone even lower than that of *Pleurograptus linearis*. She was, he believed, re-examining them in the light of better-preserved material from a similar stratigraphical horizon in the Southern Berwyns—material which appeared to indicate the Swedish zone of *Diplograptus pristis*. The Authors thought that in the western part of the Northern Berwyn outcrop, the sequence from Caradocian to Ashgillian was probably complete; but there was not enough palæontological evidence to prove this conclusively.

The term 'nodal anticline' referred to the supposed function of the anticlinal cores of Ordovician, as hard knots relative to the less-resistant Silurian strata; the term 'anticlinal buttress' had been suggested for the projection of the Berwyn Anticline, which was necessitated by the sharp difference in strike in the Central-Wales Syncline and in the Llangollen Synclinorium, and by the pitch of the latter.

The Authors had traced the Corwen Grit from Corwen to Glyn-Ceiriog, and found that near Glyn the massive uncleaved Corwen Grit overlies part of the Glyn Grit; but they regarded it as a lithological variation of the upper part of the Glyn Grit of Glyn-Ceiriog.

5. *The* CARBONIFEROUS LIMESTONE (AVONIAN) *of* BROADFIELD DOWN (SOMERSET). By FREDERICK STRETTON WALLIS, M.Sc., F.G.S. (Read January 18th, 1922.)

[Abstract.]

THE greatly denuded periclinal uplift of Broadfield Down is mapped and described in terms of Vaughan's system of zonal classification of the Avonian. All zones, with the exception of K, are present, and subzones Z_1 and D_1, hitherto unrecorded from this area, are proved to occur.

A well-marked faunal assemblage ('Fossiliferous Level'), of no great vertical extent, is described from the top of S_1, and is shown to constitute in this area a datum-line, useful in the field, for the determination of the junction between the S_1 and S_2 subzones.

Pustula elegans (M'Coy) is here for the first time recorded from the S_1 subzone in the eastern part of the South-Western Province.

Both lithologically and palæontologically the area holds an intermediate position, and forms a link between the developments of the Bristol and the Mendip areas. Thus C_2 of Broadfield Down is composed of fossiliferous, massive, grey limestones similar to that of C_2 of the Mendip area, while the lower part of C_1 is directly comparable with the *Laminosa* Dolomites of the Bristol area.

The non-occurrence of igneous rocks at the head of Goblin Coombe, where normally they would be expected to occur, is explained by a system of thrust-faulting from the South.

DISCUSSION.

Prof. S. H. REYNOLDS referred to the fact that, almost wherever detailed mapping of the Carboniferous Limestone of the Bristol district was undertaken, evidence of reversed faulting of pre-Triassic date was obtained. By considering certain other faults of Goblin Combe to be reversed, the Author had provided an adequate explanation of the non-occurrence of the igneous horizon at certain spots where evidence of its presence would have been expected.

Mr. E. E. L. DIXON remarked that, thanks to the inspiring work of Vaughan and the energy of Prof. Reynolds, the Bristol school of geology, and other workers, a clear insight into the geography of Lower Carboniferous time was being rapidly gained. He was glad to see this important link between Bristol on the north and the Mendips on the south so thoroughly described. After asking for details of the lithological characters of Horizon γ, he mentioned that the change in the facies of C_1 and C_2 as one goes south from Bristol could be paralleled in Gower and Pembrokeshire. The thickening and also the ultimate disappearance of the *Caninia* Oolite were results of the southward deepening of

the Lower Carboniferous sea. The disappearance of the lagoon-phase in C_2, so well-developed in the Avon Section, was due to the same cause. He asked whether anything further had been learnt as to the presence of sandstones and grits in the D Zone. These became increasingly important, and entered at progressively lower horizons of the Upper Avonian north of Bristol, until in the Forest of Dean, as Principal T. F. Sibly had shown, and on Titterstone-Clee Hill, they constituted practically the whole of that formation which, in consequence, had in those two districts the characters of Millstone Grit, and as such had been described. The northward increase of sand and pebbles indicated that the Bristol district lay in Upper Avonian times off the mouth of a southward flowing river.

The Author thanked the Fellows for their kind reception of his paper, and, in reply to Mr. Dixon, said that Horizon γ was well defined in Broadfield Down, and consisted entirely of limestone of the 'petit granit' type. The exposures in the D zone were scanty and poor, and included no arenaceous type of sediment such as occurred at Wickwar (12 miles north of Bristol), and to a less degree in the Avon section.

The pre-Triassic landscape was being revealed by erosion in all the Carboniferous-Limestone uplifts of the Bristol district. Many of the old pre-Triassic valleys were still filled up with Dolomitic Conglomerate.

[July 4th, 1922.]

6. *On* Certain Xenolithic Tertiary Minor Intrusions *in the* Island *of* Mull (Argyllshire). By Herbert Henry Thomas, M.A., Sc.D., V.P.G.S.; with Chemical Analyses by Ernest George Radley, F.C.S. (Read May 19th, 1920.)

[Plates VI–X.]

Contents.

I. Introduction.

In the years 1910 & 1911, the officers of the Scottish branch of H.M. Geological Survey, while engaged on a survey of that portion of the Island of Mull which lies south of Loch Scridain, were impressed by the great number of minor intrusions of a tholeiitic and andesitic character which penetrate the western part of the Tertiary lava-field. These rocks were described as being, for the greater part, of one type: namely, olivine-free dolerites or tholeiites, of which many have pitchstone centres, and in which a sheath-and-core structure is frequently developed.[1]

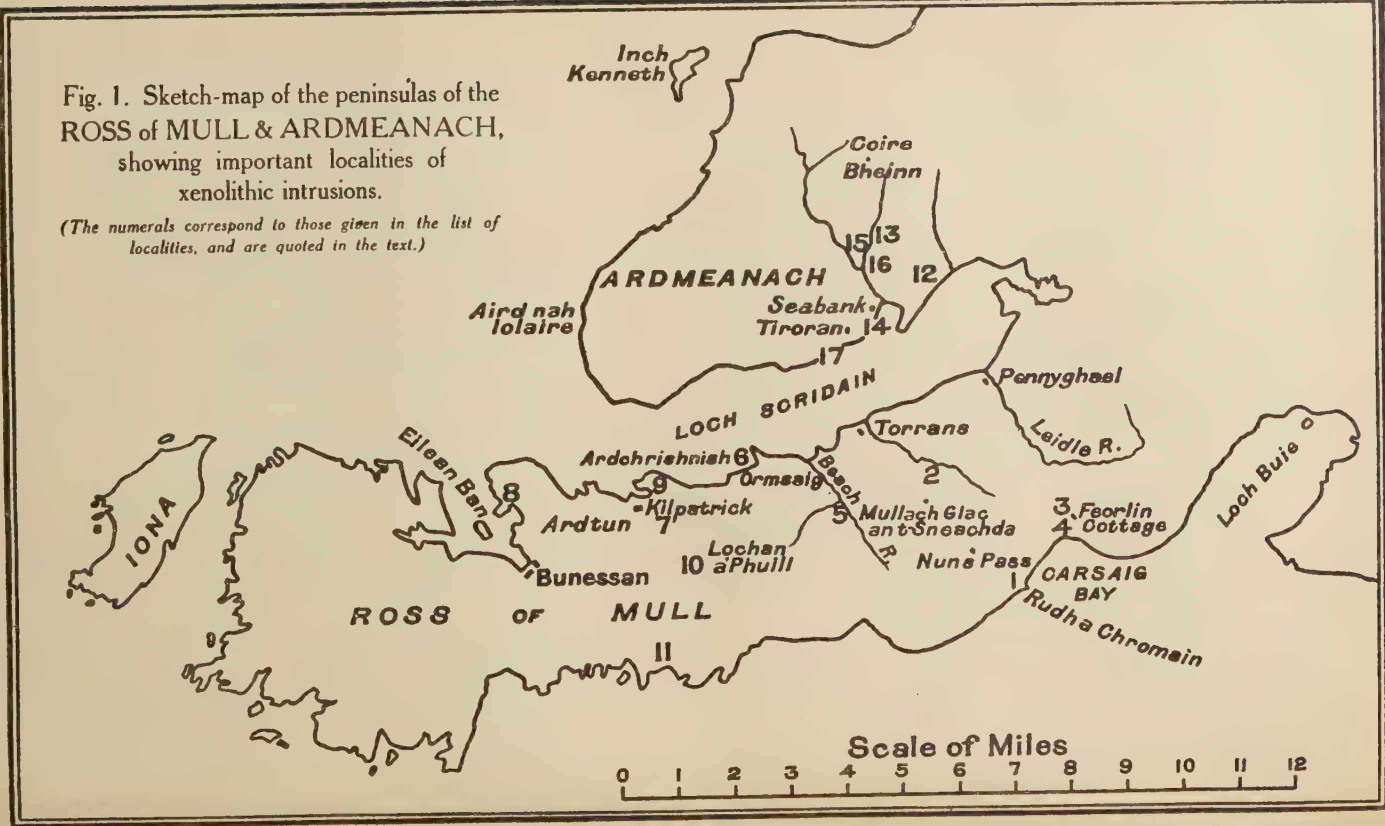
Mr. E. M. Anderson noted the occurrence within them of xenoliths of apparently fused or baked sandstone, and also recorded certain nodular masses of bytownite and some ferromagnesian mineral which he compared with similar masses, collected by the late C. T. Clough and described by Dr. J. S. Flett, from a tholeiitic intrusion at Traigh Bhan an Sgoir[2] (Traigh Bhan na Sgurra, Locality 11, fig. 1, p. 230).

[1] B. Lightfoot, 'Summary of Progress for 1910' Mem. Geol. Surv. 1911, p. 30; E. M. Anderson, 'Summary of Progress for 1911' Mem. Geol. Surv. 1912, p. 34.

[2] 'The Geology of Colonsay & Oronsay, with part of the Ross of Mull' Mem. Geol. Surv. 1911, p. 92.

Fig. 1. Sketch-map of the peninsulas of the ROSS of MULL & ARDMEANACH, showing important localities of xenolithic intrusions.

(The numerals correspond to those given in the list of localities, and are quoted in the text.)



In 1912 Mr. Anderson discovered in the bed of a tributary of Abhuinn nan Torr (Locality 2) an exposure of a rock that contained abundant small plates of a deep-blue mineral. The rock was submitted to me for examination, and, after isolation, the blue mineral proved to be corundum of the sapphire-variety. Further work on this locality, and some excavation, yielded a series of most interesting specimens that proved clearly the abnormal and intensely xenolithic character of the rock in question; but the relation of the xenolithic mass to the surrounding rocks was unfortunately obscured by surface-accumulations.

Later in the same year, Mr. G. V. Wilson & Mr. D. Tait[1] observed sapphire-bearing xenoliths among the beach-pebbles on the shore of Carsaig Bay, south-west of Carsaig village; following this clue, they detected the parent source of these xenoliths in a composite sill that cuts through the Jurassic sandstones and Tertiary lavas about a mile and a half south-west of Carsaig, and forms the low promontory of Rudh' a'Chromain (Locality 1).

As the survey of the western portion of Mull progressed, other sills with sapphire-bearing xenoliths were encountered by E. M. Anderson & C. T. Clough[2]: most of them lay, as before, in the peninsular region south of Loch Scridain; but a few others occurred on the northern side of the Loch, in the neighbourhood of Tiroran.

All the material collected by the officers of the Survey was handed to me for examination, and was supplemented by collections which I made when visiting the island in 1913 and 1914.

The beauty of the xenoliths and the occurrence of such metamorphic minerals as corundum, spinel, sillimanite, cordierite, and anorthite make these inclusions in themselves pre-eminently worthy of petrographical description; but, at the same time, an almost unparalleled opportunity offers itself for the study of the progressive metamorphic changes wrought in xenolithic material by an igneous magma of basic composition.

The object of the present communication is, therefore, twofold: first, to describe in some detail the complex mineral assemblages that constitute the xenoliths of these tholeiitic intrusions; and, secondly, to discuss the relation of the individual minerals to each other and to the igneous magma that chemically and physically controlled their formation.

II. The Intrusions.

General Description, Distribution, and Petrography.

All the xenolithic intrusions that form the subject of this paper occur relatively close together in the south-western portion of the Tertiary lava-field, in that part of the Ross of Mull which lies between Carsaig and Pennyghael on the east, and Bunessan on the west. Also, to a less extent, they have been met with north of Loch Scridain, around Tiroran in the peninsula of Ardmeanach.

[1] 'Summary of Progress for 1912' Mem. Geol. Surv. 1913, pp. 48 & 66.

[2] 'Summary of Progress for 1914' *Ibid.* 1915, p. 34.

List of Localities.

1. Rudh' a'Chromain and Nuns' Pass, Carsaig.
2. Bed of small stream, tributary to Abhuinn nan Torr, 1100 yards north of the cairn on Mullach Glac an t'Sneachda.
3. Streamlet on the northern side of a plantation, 1 furlong north of Feorlein Cottage, Carsaig.
4. Old Road, 100 yards north-west of Feorlein Cottage, Carsaig.
5. Close to Beach River, 500 yards above the junction with Abhuinn an Easa' Mhoir.
6. Coast, 1165 yards slightly north of west of Ormsaig.
7. 2600 feet east-south-east, and 1850 feet south-east by south of Kilpatrick.
8. 2560 feet north-north-east by north of the northern end of Eilean Ban.
9. 1980 feet north of west of Ardchrishnish.
10. 1150 feet east-north-east of Lochan a'Phuill.
11. 55 and 85 yards north-east of the north-eastern end of Traigh Bhan an Sgoir.
12. Shore, a quarter of a mile south-west from the mouth of Allt na Coille Moire.

13 & 15. Allt a'Mhuchaidh, 100 yards above the bridge.

14. 400 yards south of Seabank Villa.
16. Abhuinn Bail' a'Mhuilinn, 100 to 200 yards above the bridge.
17. 700 yards south-west of Tiroran.

To the foregoing list could be added many other localities within the same region, but those enumerated afford thoroughly representative examples, and will be found sufficient for investigators who wish to study these intrusions in the field. Further, it is from these localities that the bulk of the xenolithic material has been collected; and, in order to guide future workers, they have been indicated on the appended small-scale map (fig. 1, p. 230)[1] under their respective numbers.

An excellent and fully exposed example of the xenolithic intrusions is the composite sill that forms the low promontory of Rudh' a'Chromain, west of Carsaig (Locality 1): here the components of the sill can be studied in detail, and their relative ages demonstrated. Further, the relation of the sill as a whole to the rocks into which it has been intruded is particularly clear, and the occurrence is easily located. For these reasons this sill may be taken as the type with which to compare the other xenolithic intrusions, and its petrography will be described in some detail.

It consists of an acid central member, 20 to 30 feet thick, which is bounded on each side by lateral basic members of less, but unequal, thickness. It may be traced across the foreshore and the raised-beach platform to the cliff below Nuns' Pass, where it is either faulted or rapidly cuts across the Tertiary lavas, to a position in the cliff about 100 feet above sea-level.

On the west its basic lower portion is in contact with the Carsaig Sandstone (Jurassic); but on the east the upper basic

[1] A sketch-map showing the two original localities for sapphire-bearing xenoliths was reproduced in the 'Summary of Progress for 1912' Mem. Geol. Surv. 1913, p. 48.

margin is chilled against an earlier intrusion of bostonite, which separates it from the Carsaig Sandstone in that direction.

The details of the intrusion are illustrated in the sketches (figs. 2 & 3, p. 234) made by Mr. D. Tait.

The central portion of the sill is a pale-grey rock, finely crystalline for the greater part, without any marked porphyritic constituents. Locally, it is distinctly hyaline in texture, and, like many of the pitchstones of Mull, has developed the characteristic 'sheath-and-core' structure of these rocks.[1]

Xenoliths occur sparingly throughout its mass, but perhaps are more prevalent in the somewhat less acid selvages that adjoin the basic members on each side. The xenoliths are mainly of sandstone, and range up to 6 inches or so in longest diameter. Large xenoliths of both shale and sandstone occur in a more central position, and may measure several feet in diameter, with an average of about 2 feet.

The basic marginal members of the sill clearly antedate the acid interior. They differ somewhat one from the other in relative thickness, and in the number and character of the contained xenoliths. In regard to texture, they appear to be fine-grained dark-grey to dark-brown rocks, exhibiting a more compact facies at their outer contacts with the Carsaig Sandstone and the bostonite respectively.

The upper basic member is divisible into two zones. The outer zone, about 4 to 6 feet thick, contains abundant cognate xenoliths of gabbroid character. These xenoliths are of all sizes, from quite small dimensions to a foot or so in diameter. The inner zone of similar material, ranging from 2½ to 5 feet in thickness, is densely crowded with accidental aluminous xenoliths of all shapes, which range in size from an inch to 4 feet in greatest dimension. The lower basic member of the sill is from 2 to 5 feet thick, and is characterized particularly by the size and abundance of its cognate xenoliths and the relative rarity of accidental xenoliths. The concentration of cognate xenoliths in the lower portion of the Traigh-Bhan-na-Sgurra sheet is a point worthy of notice in this connexion.[2]

The acid interior of the sill is, as a whole, a compact pale-grey to brownish-grey rock, which, towards its external margins, for a foot or two, darkens in colour, apparently becomes slightly more basic, and carries numerous xenoliths of sandstone. These more basic and relatively thin marginal portions are of the nature of inninmorite, a type of Mull pitchstone characterized by the presence of uniaxial augite and described in 1915 in the paper already cited by Mr. E. M. Anderson & Mr. E. G. Radley.[3]

[1] E. M. Anderson & E. G. Radley, 'The Pitchstones of Mull & their Genesis' Q. J. G. S. vol. lxxi (1915–16), p. 210.

[2] J. S. Flett, 'Geology of Colonsay & Oronsay, with part of the Ross of Mull' Mem. Geol. Surv. 1911, p. 92.

[3] 'The Pitchstones of Mull & their Genesis' Q. J. G. S. vol. lxxi (1915–16) p. 209; see also A. F. Hallimond, 'Optically Uniaxial Augite from Mull' Min. Mag. vol. xvii (1914) p. 97.

Fig. 2.—*Section across the xenolithic composite sill, Rudh' a' Chromain.*
(Length of section=about 20 yards.)

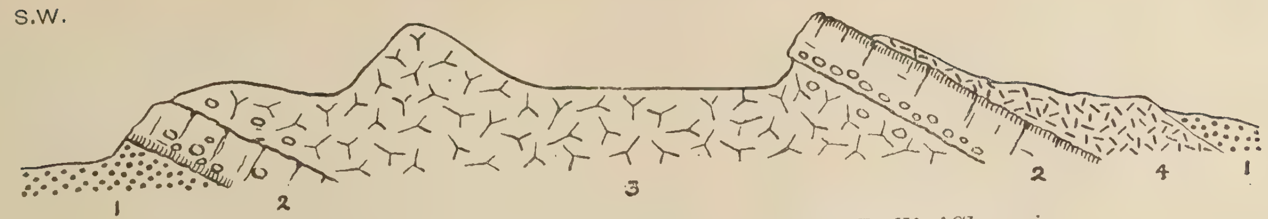


Fig. 3.—*Exposure of the xenolithic sill on the foreshore, Rudh' a' Chromain.*
(Length of section=about 8 yards.)

1=Carsaig Sandstone (Jurassic).
3=Acid central portion of sill.

2=Basic margin of sill, with xenoliths.
4=Bostonite of an earlier intrusion.

Where vitreous, the rock consists of small porphyritic crystals of labradorite and less frequent uniaxial augite (usually pseudomorphed in serpentine or calcite) in a brownish glass traversed in all directions by acicular crystals of augite and skeletal growths of magnetite. In portions of the rock that have undergone greater devitrification the ground-mass carries the same phenocrysts and acicular augite, but may be seen to contain alkali-felspar and quartz. The central and greater portion of the acid interior is a grey rock, locally vitreous and often showing the 'sheath-and-core' structure characteristic of many of the Mull pitchstones.[1] The acid portions vary from rhyolite to felsite, but are always very closely related to rocks classed with the extremely acid types of inninmorite. They consist of small porphyritic crystals of acid labradorite in a glassy base which, like that of the inninmorite, is traversed by blade-like crystals of a greenish augite. Even in the glassy portions (Pl. VI, fig. 1) small devitrified areas are of frequent occurrence, and are composed of felspar-crystals, of less basic composition than the phenocrysts, which are often grouped in a radial or subvariolitic manner.

When more completely devitrified (Pl. VI, fig. 2) the rock is lighter in colour; the base contains little glass, its place being taken by a feathery felspathic mass which is still traversed by the acicular crystals of augite, but holds (in addition to acid plagioclase) some orthoclase and a little free quartz.

The analysis of a felsite closely related to inninmorite, made by Mr. F. R. Ennos, of the Government Laboratory, and tabulated in col. 1 of the analyses on p. 236, although from another locality, may be taken to represent closely the composition of the acid interior of the Rudh' a'Chromain sill.

The normal stony basic portion (Pl. VI, fig. 4) consists of somewhat elongated irregularly-formed crystals of aluminous augite, which tend to assume a prismatic habit, and felspar, with which the augite often has subophitic relationship.

The felspar is a basic labradorite zoned with plagioclase of composition varying to that of oligoclase. These two minerals make the bulk of the rock, and together give rise either to a sub-variolitic or to an intersertal structure. The interstitial matter is devitrified, and consists of acid plagioclase and quartz. It contains a relatively small amount of magnetite, and abundant apatite in the form of slender needles.

In the more vitreous portion (Pl. VI, fig. 3), in which cognate xenoliths appear to be the more prevalent, the rock has a definitely intersertal structure.

The varieties met with in the basic margins are all closely related. Their composition is clearly on the border-line between that of basalt and augite-andesite; and this, combined with a frequently well-marked intersertal structure, warrants their inclusion among the tholeiites. In Mull it has been found that 55 per

[1] E. M. Anderson & E. G. Radley, *op. supra cit.* pp. 210, 211.

cent. of silica furnishes a very natural acid limit to the tholeiites. Beyond that one meets with the andesitic rocks already alluded to as leidleites and inninmorites, and also other types distinguished by the degree of crystallization. The Rhud' a'Chromain tholeiitic margins have a very close analogy to leidleite, as shown by their tendency to acicular and variolitic structure, and this agrees with the silica percentage shown in Analysis II. In the Geological Survey Memoir on the 'Geology of Colonsay & Oronsay with part of the Ross of Mull' 1911, p. 92, the xenolithic sheet of Traigh Bhan na Sgurra is described by Dr. Flett as a dolerite of the olivine-free type, and is exactly comparable with the basic margins of the Rudh' a'Chromain sill.

The composition of the stony portion of the Rudh' a'Chromain sill is recorded in Analysis II, by Mr. Radley. Compared with normal andesites the silica percentage is relatively low, and there are other divergences on the basalt side.

Analyses of Xenolithic Sills and Xenoliths.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	70·70	53·97	38·67	49·74
TiO_2	1·27	1·24	0·90	1·49
Al_2O_3	11·78	14·65	37·27	34·99 *
Fe_2O_3	1·32	3·62	2·78	1·53
FeO	3·45	6·32	5·07	0·34
MnO	0·07	0·30	0·17	0·15
$(CoNi)O$	—	nt. fd.	nt. fd.	nt. fd.
BaO	—	0·04	—	nt. fd.
CaO	1·30	7·98	4·65	0·88
MgO	0·53	4·49	2·35	0·66
K_2O	4·71	1·52	3·01	1·72
Na_2O	2·48	2·54	3·63	3·76
Li_2O	nt. fd.	trace	nt. fd.	trace
H_2O at 105° C.	0·50	1·92	0·22	0·61
H_2O above 105° C.	1·14	0·94	1·63	3·44
P_2O_5	0·26	0·27	—	0·86
FeS_2	—	0·09	—	nt. fd.
CO_2	0·51	0·51	—	0·04
S	0·08	—	—	—
Totals	100·10	100·40	100·35	100·21

I. Felsite related to inninmorite. Acid sill from an exposure south of Coire Buidhe, about half a mile north of Carsaig (S. 18464); 'Summary of Progress for 1915' Mem. Geol. Surv. 1916, p. 26 (Anal. F. R. Ennos).

II. Tholeiite. Basic portion of composite intrusion, Rudh' a'Chromain, west side of Carsaig Bay (S. 17170); 'Summary of Progress for 1914' Mem. Geol. Surv. 1915, pp. 56, 57 (Anal. E. G. Radley).

III. Xenolith containing basic plagioclase, sillimanite, sapphire, and spinel (S. 16612), from the basic portion of the sill, Nuns' Pass, Carsaig; 'Summary of Progress for 1913' Mem. Geol. Surv. 1914, pp. 80, 81 (Anal. E. G. Radley).

IV. Sillimanite-buchite. Xenolith from the basic portion of a sill, Nuns' Pass, Carsaig; *0·48 per cent. of the alumina is present as corundum, 'Summary of Progress for 1914' Mem. Geol. Surv. 1915, pp. 56, 57 (Anal. E. G. Radley).

The majority of the xenolithic sills are not markedly composite,

although they often have a more or less vitreous centre (leidleite) with stony marginal portions. The xenoliths are generally concentrated near the margins; and their containing matrix, where investigated, consists of tholeiite similar to the lateral members of the Rudh' a'Chromain intrusion.

The intrusion of Mullach Glac an t'Sneachda, in which sapphire was first detected, calls for special notice on account of its unusual character. It is unfortunately but indifferently exposed, and its relations to adjoining rocks are somewhat obscure. It appears as a dark-grey amygdaloidal rock of fine texture and igneous aspect. It is studded with small lustrous plates of sapphire, and packed with aluminous and siliceous xenoliths of all sizes. A mass of siliceous material 6 feet long exposed by the side of the burn is clearly a xenolith. Cognate xenoliths are unrepresented, except in the form of isolated and often broken crystals of dark-green hypersthene and less frequently of augite, indicating an early crystalline separation from a tholeiitic magma similar to that which gave rise to the cognate xenoliths of Rudh' a'Chromain. The chief anomaly is the dark matrix, which, under the microscope, is seen not to be a true igneous rock, but to be a sillimanite-buchite (p. 240) modified by more or less complete admixture with igneous material. The apparent porphyritic crystals are all broken bytownite and anorthite, derived from highly crystalline aluminous xenoliths (p. 241), and, therefore, themselves of xenolithic nature.

That the rock was intruded as a molten or semi-molten mass is proved by its numerous vesicular cavities, now filled with zeolites and other low-temperature minerals.

The amount of xenolithic material carried by this intrusion is very considerable: for, apart from the abundant accidental xenoliths held by the pseudo-igneous matrix, the matrix itself is largely composed of fused sedimentary material (sillimanite-buchite), modified to some extent and doubtless rendered more fluid by admixture with a tholeiitic magma. It will be seen in the sequel that such an intrusion would result from the squeezing-upwards of the viscous semi-fused material that formed the wall of the magma-basin (p. 250).

A similar type of intrusion would appear to be represented in the kersantite of Michaelstein,[1] which forms a dyke of obviously mixed igneous and sedimentary material full of a variety of minerals foreign to the rock.

Generally speaking, the tholeiitic intrusions have produced little thermal alteration of the rocks into which they have been ultimately injected, although the sill at Traigh Bhan na Sgurra is a notable exception. The intrusions are seldom of large dimensions, their type of crystallization indicates rapid consolidation, and we

[1] M. Koch, 'Die Kersantite des Unterharzes' Jahrb. K. Preuss. Geol. Landesanst. 1886, p. 44.

can be fairly sure that their intrusion-temperature was not particularly high. The tholeiite of Rudh' a'Chromain, however, at its junction with the Carsaig Sandstone, has for a few millimetres thermally altered the sedimentary rock. The action has been to produce an interstitial melt between the component grains of the sandstone, which has attacked and dissolved the quartz, with the subsequent crystallization of tridymite-fringes around the undissolved portions of the grains. The tridymite has reverted to quartz which, while being in optical continuity with the quartz of the original grain, retains the form of tridymite. This phenomenon is much better displayed by the quartz-grains in the siliceous xenoliths, the metamorphism of which is of a more intense character (see p. 240).

III. The Cognate Xenoliths (Enclaves Homœogènes).

Cognate xenoliths are a striking feature of the basic portions of the Rudh' a'Chromain and Nuns' Pass sill, and of the tholeiitic intrusions of several other localities under consideration. Such xenoliths were first described from the tholeiites of this region by Dr. Flett, who recognized two types: one consisting of bytownite and pale-green augite, and the other of bytownite and a nearly colourless enstatite or bronzite.[1]

In the Rudh' a'Chromain sill they occur as dark coarsely-crystalline patches, sharply marked off from the more finely-grained tholeiite that envelops them. As was noted in the similar occurrence of Traigh Bhan na Sgurra, they show a distinct tendency to congregate in the lower portion of the sill, suggesting a gravitational concentration. They consist commonly of bytownite and hypersthene. The hypersthene-crystals are often sharply idiomorphic (Pl. VI, fig. 6) and have moulded upon them, or occasionally include, an optically positive basic plagioclase (basic labradorite or bytownite).

Less frequently a dark-green augite takes the place of the rhombic pyroxene (Pl. VI, fig. 5), and like it is usually idiomorphic towards the bytownite (16612*a*, 17173).[2] In some cases olivine appears to have been present, but is now represented by serpentinous and calcitic pseudomorphs (17174). An orthorhombic and a monoclinic pyroxene are sometimes, though rarely, associated in the same xenolith.

Hypersthene, presumably derived from cognate xenoliths, occurs in the intrusion of Mullach Glac an t'Sneachda (Locality 2), while coarse aggregates of bytownite and augite have been met with at Seabank Villa (Locality 14), where some of the augite-crystals are sharply idiomorphic (18530), and occasionally measure nearly 2 inches in length.

[1] 'Geology of Colonsay & Oronsay, with part of the Ross of Mull' Mem. Geol. Surv. 1911, p. 92.

[2] These numerals in parentheses refer to the rock-slices in the collections of the Geological Survey.

IV. The Accidental Xenoliths (Enclaves Enallogènes).

The greater number of accidental xenoliths are carried by tholeiitic sheets, or in the basic tholeiitic portions of the composite intrusions. They are, however, not entirely restricted to the more basic rocks, and may be found in less numbers and in a somewhat different state of metamorphism in the more acid portions of some of the sills, especially that of Rudh' a'Chromain.

They may be divided into two classes, according to their nature, which we may designate respectively as (*a*) siliceous and (*b*) aluminous. The former class includes such xenoliths as arise from sandstones and granitic or gneissose rocks. while the latter class is exemplified by xenoliths that appear to have had their origin in aluminous shales of fairly constant composition. The aluminous xenoliths, besides occurring in greater quantity, also have greater average dimensions, and it is with these that we are chiefly concerned.

(*a*) The Siliceous Xenoliths.

These present no particularly new features, and the majority of the changes that they have undergone have been dealt with in a most complete manner by other authors, more particularly by Prof. A. F. A. Lacroix.[1] A few points, however, are worthy of mention, especially those indicating the selective fusion of the felspathic constituents and the almost universal formation of tridymite around grains of undissolved quartz when the interstitial melt is acid. The separation of augite and rhombic pyroxene around undissolved quartz from a sufficiently basic melt, or from an interstitial melt modified by transfusion of basic igneous material, is too well known to call for further comment.

Sandstones, granitoid rocks, and what presumably have been gneisses are all represented among the xenoliths, and all show a similar and relatively simple type of metamorphism. Sandstones are the most prevalent, being distinctly common in the intrusions of Localities 1 & 2.

The Carsaig Sandstone, or some similar rock, has furnished a considerable number of xenoliths to the sills, and the nature of the metamorphism is identical with, but greater in degree than, that exhibited by the Carsaig Sandstone in contact with the intrusive tholeiite of Rudh' a'Chromain. The metamorphism is usually unaccompanied by any transfusion of igneous material, and has been produced by purely thermal agencies. Felspathic constituents at the elevated temperature thus originated have given rise to an interstitial melt, which attacked the surfaces of the quartz-grains and thus became enriched with dissolved silica. Crystals of tridymite separated from the melt, and attaching themselves at all angles to the undissolved grains, formed fringes. The residual melt consolidated as glass. The tridymite-crystals have now

[1] 'Les Enclaves des Roches Volcaniques' Ann. Acad. Mâcon, vol. x, 1893.

reverted to quartz, and usually extinguish simultaneously with the quartz-grain that they fringe; but, recalling the identical structures produced in fused ganisters and other siliceous refractories,[1] we can have no doubt as to their original character.

Dr. J. S. Flett,[2] some years ago, in a xenolith from Traigh Bhan na Sgurra, described fringes identical with those mentioned above, but doubtfully attributed to them a different origin.

Of the recently collected material one of the best examples of such a siliceous xenolith comes from Feorlein Cottage, Carsaig (Locality 3), and is illustrated in Pl. VII, fig. 5. The quartz has suffered considerable solution by the interstitial melt; but, on cooling, large plates of tridymite have been deposited upon the undissolved quartz, and similar crystals have separated from the melt now represented by the glassy matrix.

The amount of glass found in these siliceous xenoliths is variable, and appears to increase according to the amount of felspathic constituents in the original rock, also with transfusion of igneous material which would tend to lower the melting-point. The presence of igneous material usually betrays itself by the deeper colour of the interstitial glass, and by the separation of minute crystals of cordierite. A beautiful example of the ready fusion of the felspathic constituents and the formation of a copious interstitial melt has been furnished by a sandstone xenolith (20763) collected by Mr. E. M. Anderson from a tholeiite-sill near Bunessan. A sandstone xenolith metamorphosed by a tholeiitic magma, and modified to some extent by transfusion of igneous material, is illustrated by an example from south-east of Gortein Driseach, between Localities 2 & 5 (Pl. VII, fig. 6).

(*b*) The Aluminous Xenoliths.

(i) General Description.

The aluminous xenoliths present three distinct types, and may be grouped under three separate headings, according to their structure and mineral constituents, and incidentally according to the manner and degree of modification induced by the igneous magma. The following types, which occur either in close dependent association or as separate units, can be readily recognized:—

(1) The sillimanite- and cordierite-buchites.
(2) The anorthite-corundum-spinel assemblage.
(3) The cordierite-sillimanite-spinel assemblage.

(1) The buchites (or basalt-jaspers of foreign writers) are composed essentially of glass with one or more characteristic crystalline phases, such as sillimanite, cordierite, etc. They are

[1] See H. H. Thomas, A. F. Hallimond, & E. G. Radley, 'Mineral Resources of Great Britain' Mem. Geol. Surv. vol. xvi (1920) p. 60 & pl. iv.

[2] 'Geology of Colonsay & Oronsay, with part of the Ross of Mull' Mem. Geol. Surv. 1911, p. 95 & pl. vi, fig. 5.

produced by the simple fusion and subsequent consolidation of sedimentary material without or with admixture of magmatic matter supplied by the invading igneous rock. Such buchites have been described frequently, especially by Prof. A. Lacroix and Dr. Alfred Harker; and, later, by Dr. J. S. Flett, in association with the Tertiary dykes of the Oban and Dalmally district.[1]

The sillimanite-buchites, of which many examples have been collected from the various localities, are compact, vitreous, grey-blue or lilac-coloured rocks, consisting of glass in which the abundant minute needles of sillimanite are usually arranged in a parallel manner (Pl. VII, figs. 1 & 2).

The cordierite-buchites are most often black, and cordierite is either the chief or the only crystalline constituent (Pl. VII, fig. 3).

(2) What has been termed the anorthite-corundum-spinel assemblage is an almost holocrystalline mixture of these minerals, and is extremely prevalent in the intrusions under description. It is clearly of xenolithic nature, and is well illustrated by Pl. VIII, fig. 2.

(3) The cordierite-sillimanite-spinel assemblage is less common than Group 2, and results presumably from somewhat special conditions that are discussed later.

The relation and interdependence of the anorthite-corundum-spinel assemblage and the sillimanite-buchites are clearly indicated.

In some of the more symmetrical xenolithic masses it can be demonstrated that the innermost portion is a dark-grey or dull lilac-coloured rock of vitreous character (sillimanite-buchite). This vitreous mass, followed towards its outer margin, is seen first to contain scattered felspar-crystals, often skeletal in form, and then, by the felspars becoming more frequent and better formed, to develop into a more or less completely crystalline felspathic zone. This zone, often several inches thick, and rich in corundum and spinel, normally separates the buchite from the enclosing tholeiite.

The felspathic portion (anorthite-corundum-spinel assemblage) is roughly divisible into two—an inner sub-zone in which corundum in the form of sapphire is abundant and spinel subordinate, and an outer sub-zone in which the ratio of these two minerals one to the other is reversed.

The line of demarcation between the holocrystalline portion of the xenolith and the surrounding igneous rock is usually quite sharp, and the igneous rock rarely shows any compositional variation that can be attributed to direct action of the foreign inclusion.

In practically every xenolith of any size that has been examined a zonal arrangement can, in some measure, be made out, but not always of a symmetrical character (p. 249). Sometimes the inner vitreous portion (buchite) is reduced to a minimum, and at other times the outer crystalline zone is thin or of varying thickness.

[1] 'Geology of the Country near Oban & Dalmally' Mem. Geol. Surv. 1908, pp. 129-31; see also 'Geology of Colonsay & Oronsay, with part of the Ross of Mull' Mem. Geol. Surv. 1911, pp. 93–95.

In small xenoliths the buchite may be entirely unrepresented, and the whole of the inclusion may then be composed of plagioclase with accompanying corundum and spinel showing a small amount of interstitial glass.

I shall now briefly describe the chief minerals that enter into the composition of the aluminous xenoliths, and at the same time discuss in turn their probable mode of origin and relation to the other minerals with which they are associated.

(ii) The Minerals of the Xenoliths: their Mode of Formation and Mutual Relations.

Corundum.—The corundum of the xenoliths nearly always occurs as deep-blue brilliant crystals of distinctly tabular habit. There are three modes of occurrence:—

(1) As isolated crystals in the sillimanite-buchites; (2) in close association with anorthite in the crystalline outer portions of the xenolithic masses (Pl. VIII, fig. 2); and (3) as well-formed crystals in a matrix of distinctly igneous nature, which adheres to, and penetrates, the crystalline outer zone of certain xenoliths (Pl. IX, fig. 1).

All crystals have the same general habit; they are flattened parallel to the base {0001}, and are usually rhombohedral or pyramidal in form. The prism of the second order {1120} is seldom met with, and the usual combination of forms is the base {0001} modified by the rhombohedra {1011} {3032}, or less commonly by the rhombohedra together with the pyramid {2243}.

The faces are bright, and give excellent goniometric readings, by which the identity of the forms mentioned above has been established. The basal plane is stepped or deeply striated parallel to the trace of one or other of the rhombohedral faces, giving rise to well-marked equilateral triangular areas, one within the other, which are due to oscillation in regrowth of the base and rhombohedron. In size the crystals vary from a millimetre or so, measured across the basal plane, to at least a centimetre and a half in exceptional cases. Their thickness measured along the vertical axis is usually less than half the width of the basal plane. The acutely pyramidal habit of many varieties of corundum is entirely unrepresented. The tabular habit and general simplicity of forms appear to characterize corundum of xenolithic masses, and, what practically amounts to the same thing, that which has separated from basic igneous magmas on their becoming saturated with alumina through solution of aluminous material.

Corundum such as we are considering has been fully and repeatedly described, and it will be sufficient to state that the crystals here mentioned find their closest analogue in the tabular crystals of Yogo Gulch (Montana).[1]

[1] For detailed accounts of the occurrence of this mineral, see J. H. Pratt & J. V. Lewis, 'Corundum & the Peridotites of Western North Carolina' Mem. Geol. Surv. N. Carolina, vol. i (1905) pp. 225 *et seqq.*; L. V. Pirsson, Amer. Jour. Sci. ser. 4, vol. iv (1897) p. 421; also 20th Ann. Rep. U.S. Geol. Surv. 1898 99, pt. iii (1900) pp. 552, 553.

The colour of the crystals is deep blue in thick sections, and very pale blue for the thickness of an ordinary rock-section. The pleochroism is generally quite distinct, if not strong:—

ω = pale blue. ϵ = pale greenish-blue to sea-green.

Optical anomalies are rarely met with, and twinning parallel to the fundamental rhombohedron $\{10\bar{1}1\}$, although present in some instances, is of rare occurrence.

Inclusions are general, but almost invariably consist of brownish to colourless glass, and this feature appears to be more or less characteristic of the corundum of the metamorphic and non-plutonic igneous rocks.

As regards origin, the corundum of the sillimanite-buchite represents the excess of alumina over that required for the formation of sillimanite and melt, and was the first solid phase to separate out from the fused aluminous sediment. It rarely forms as much as 1 per cent. of the buchite, and is generally below 0·5. In the case of the corundum of the anorthite-corundum-spinel assemblage that appears to interpose itself normally between the sillimanite-buchite and the magma, we find that corundum is more plentiful towards the buchite: that is to say, towards the source of the alumina. It is invariably associated with anorthite, and in a manner that points conclusively to crystallization from a common solution of these two substances. In some instances the lack of crystalline form of the corundum in association with anorthite would suggest the simultaneous crystallization of these minerals in equilibrium with each other and with the melt, and the maintenance by transfusion of an anorthite-corundum eutectic condition.

The later-formed corundum, which occurs associated with spinel and oligoclase in a matrix of more igneous character, has been formed by the separation of alumina from a partial magma enriched in alumina through the resorption of anorthite containing sillimanite (p. 244). A certain portion of the excess alumina has combined with the available magnesia and ferrous iron of the magma to form spinel (p. 248). Both corundum and spinel are often enclosed by a zone of anorthite-crystals (Pl. VIII, figs. 3 & 4), a feature noted by Prof. Lacroix in xenoliths from the Cantal region.[1]

Sillimanite.—This mineral is a common product in metamorphosed aluminous sediments; in the xenoliths under description it is, next to corundum, the earliest and most constant crystalline substance to separate from the melt produced by the fusion of the highly aluminous shales. It occurs mostly as minute needles about 1 to 2 mm. long, which are either felted together or arranged in a parallel fluxional manner in a colourless or pale violet-tinted glass.

[1] 'Les Enclaves des Roches Volcaniques' p. 190: 'On voit que lorsqu'un grand cristal de corindon ou de spinelle se produit, il est entouré d'une zone exclusivement feldspathique.'

To such an assemblage the name sillimanite-buchite is applied (p. 241).

The mineral, even in the small needles, has a characteristic pleochroism of pale pink to colourless, similar to, but less intense than, that of the larger crystals described below. Inclusions are seldom present, and then consist solely of glass.

In origin, the sillimanite is partly a product of direct vitrification and partly a primary phase separated, on fall of temperature, from the original aluminous melt. It furnishes the main source of the alumina present in the other aluminous minerals, such as anorthite, spinel, and cordierite, which are of later appearance and are dependent for their formation on the transfusion of bases from the igneous magma.[1]

Large crystals of sillimanite of a deep rose-pink colour occur in a dark glass, in association with cordierite and spinel (S. 18001a), Pl. VII, fig. 4. There is evidence that these crystals are due to the reheating of an original sillimanite-buchite, and that their size has thereby been increased.

Their most striking feature is an intense pleochroism which is bright rose-pink parallel to $\mathfrak{c}$, the long axis of the crystals, and colourless parallel to $\mathfrak{a}$ and $\mathfrak{b}$ (S. 18001). So far as I am aware, a strong pink pleochroism, recalling that of the more highly-coloured varieties of andalusite, has seldom been met with in this mineral. The only record that I can trace of a pink sillimanite is that given by Des Cloizeaux and quoted by Hintze.[2]

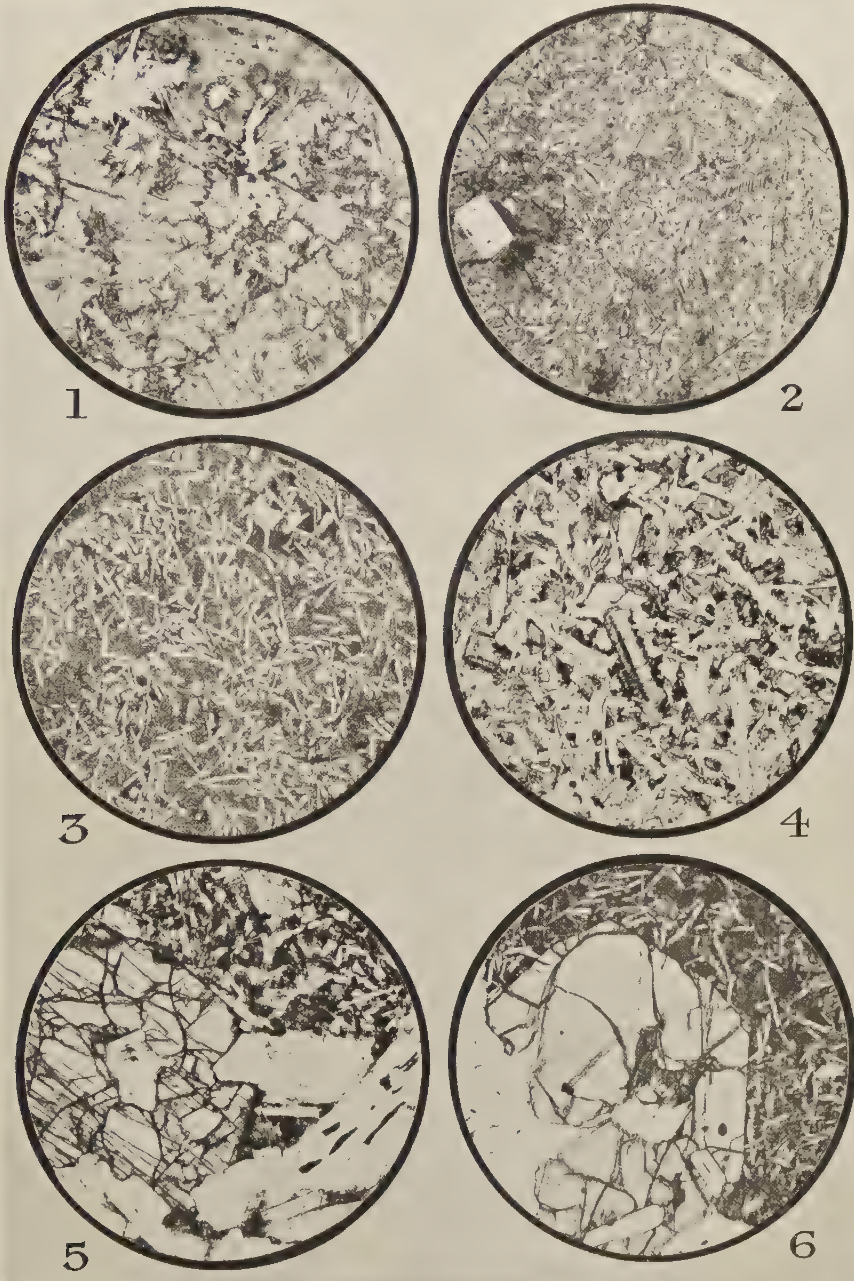
Crystallographically the mineral forms approximately rectangular prisms bounded by the face (110); these in cross-section provide diagonal directions of extinction, and show traces of the usual perfect cleavage parallel to (010).

Felspar.—The chief and earliest-formed felspar of the accidental xenoliths occurs in the complex crystalline zone (anorthite-corundum-spinel assemblage) which separates the sillimanite-buchite from the igneous rock, and resulted from the crystallization of a hybrid melt of special composition due to the mutual influence of the tholeiite-magma and fused aluminous xenolithic material. The felspars occur as large crystals, often reaching several inches in length. Near the external margin of the crystalline zone they are mutually interfering, but towards the buchite they become more distinctly separated by glassy matter and more noticeably idiomorphic.

Their formation has, to a limited extent, been attended by a resorption of the sillimanite of the buchite; but the felspars are

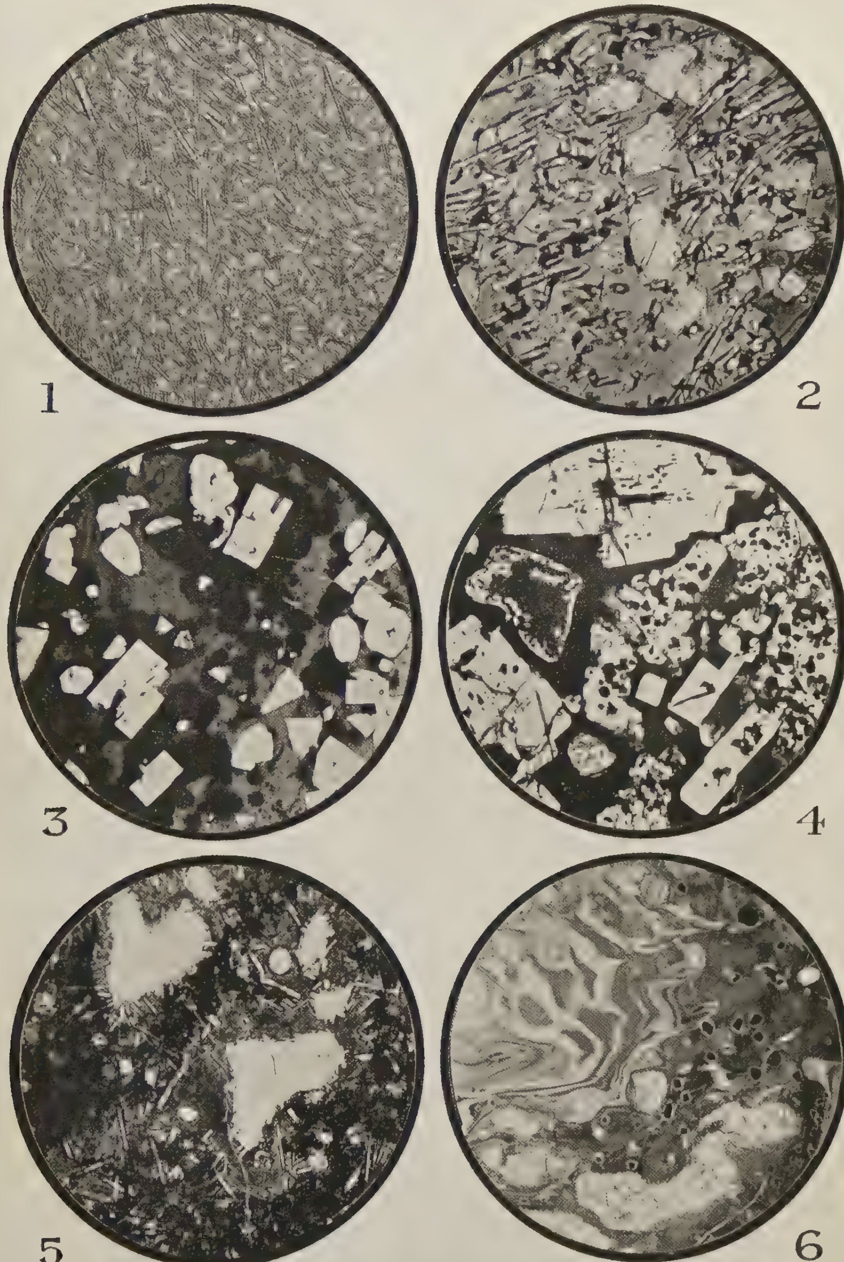
[1] G. V. Wilson, 'Notes on the Formation of certain Rock-forming Minerals in & about Glass Furnaces' Trans. Soc. Glass Technology, vol. ii (1918) p. 177.

[2] A. Des Cloizeaux, 'Manuel de Minéralogie' vol. i (1862) p 179; see also C. Hintze, 'Handbuch der Mineralogie' vol. ii (1897) p. 142: 'Zuweilen ist ein Pleochroismus wahrzunehmen: Des Cloizeaux beobachtete an Spaltungsblättchen mit dem Dichroskop ein farbloses und ein schwach rosenrothes Bild.'



J. Rhodes photomicro.

Composite Sill (Rudh' a'Chromain); Felsite; Tholeiite; and Cognate Xenoliths.

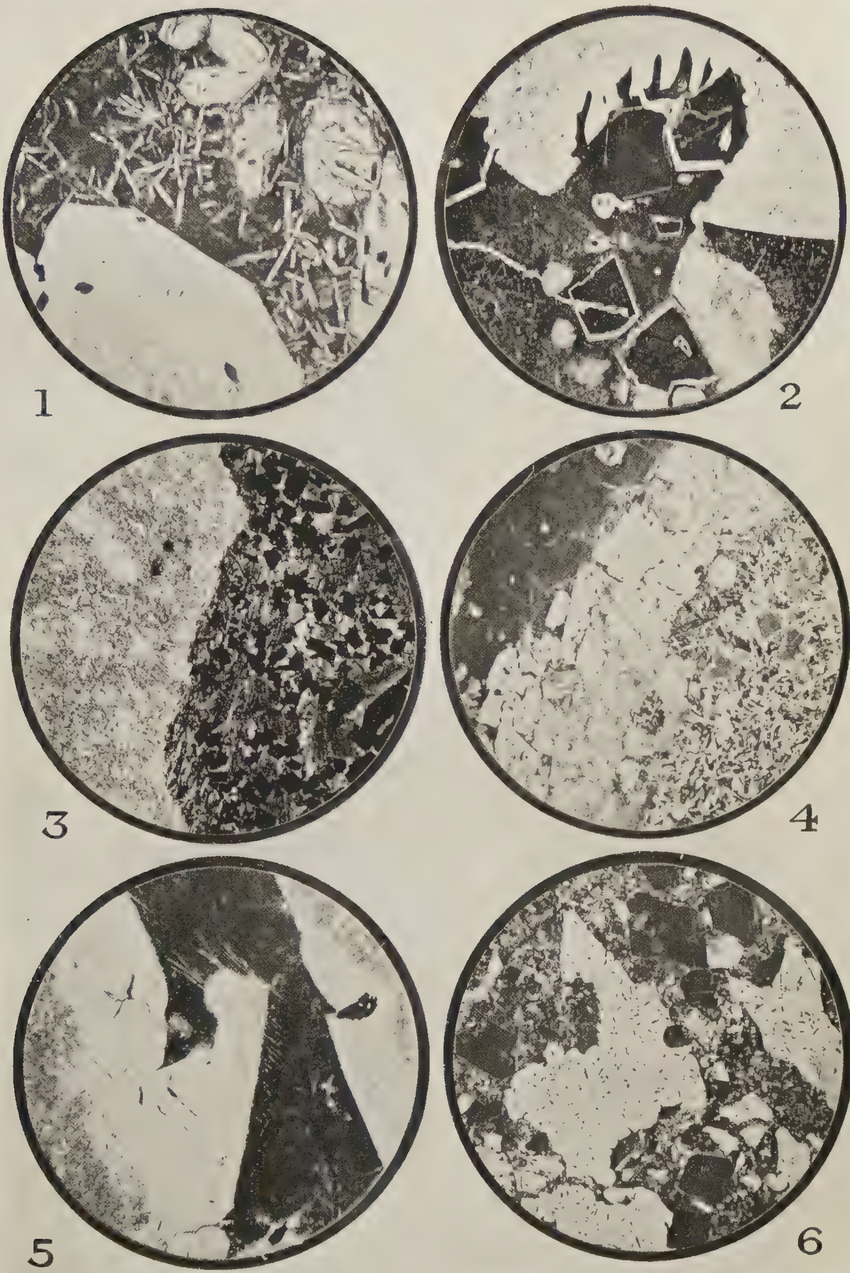


J. Rhodes photomicro.

Sillimanite- and Cordierite-Buchites, and Siliceous Xenoliths.

J. Rhodes photomicro.

ANORTHITE-SAPPHIRE-SPINEL ASSEMBLAGES.



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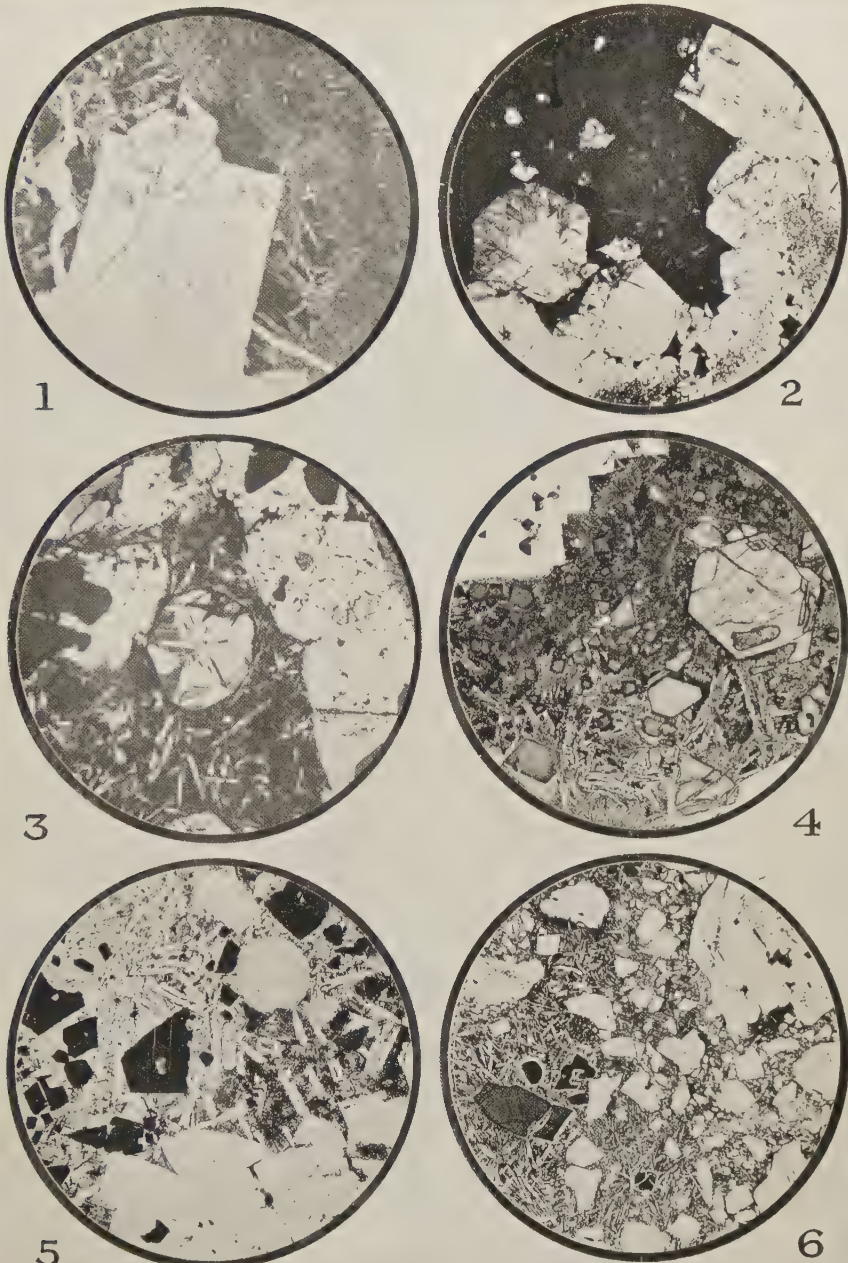
XENOLITHS INVADED AND RESORBED BY THOLEIITIC MAGMA.



J. Rhodes photomicro.

XENOLITHS INVADED AND RESORBED BY THOLEIITIC MAGMA.

usually crowded with undissolved needles of this mineral (Pl. IX, figs. 1–3, 5, & 6) which impart to the crystals a striking flesh-pink colour (p. 244). Occasionally, they are coloured a sky-blue by finely divided corundum (Pl. VIII, fig. 6). In composition they approximate closely to anorthite, and are thus more basic than the glomeroporphyritic felspars (bytownite) of the cognate xenoliths previously described (p. 238). Their formation was often accompanied by the almost simultaneous separation of corundum and spinel, in a manner that suggests that these three phases were capable of existence in equilibrium one with the other and with the melt at the time of their formation (p. 252).

The early-formed anorthite has most often undergone considerable compositional modification as the conditions of equilibrium between xenolith and magma were disturbed. There has frequently been disruption of the coarsely crystalline zone and resorption of the anorthite and its contained sillimanite. This was followed by an additional crystallization on the remaining anorthite of an increasingly acid plagioclase, which ranges through labradorite to oligoclase. Such later-formed felspar is free from included sillimanite, and the excess of alumina furnished by its resorption has separated either as corundum (sapphire) or as spinel (Pl. VIII, figs. 1, 2, & 5). Corundum, as might be expected, occurs more frequently nearer the source of alumina (buchite); while spinel crystallizes nearer the source of magnesia and iron (magma). The latest crystallization of felspar was of a rapid character, and antedated but little the intrusion of the modified xenoliths into their present position. It is usually of oligoclase composition, and may occur either as an outer zone to pre-existing more basic felspars, or as freshly grown individuals of skeletal form which have separated from the residual melt (Pl. X, figs. 4 & 5). With regard to the formation and resorption of the earlier felspars, it is interesting to note analogous processes going on in artificial melts. Mr. G. V. Wilson, writing on certain minerals formed in glass-furnaces, calls attention to the fact that felspars entering into the composition of an absorption-zone between the glass-melt and the furnace-brick (aluminous) were full of sillimanite-needles, but that the sillimanite of the melt, as of the buchite, was undergoing resorption in order to supply alumina for the formation of felspar.[1]

Cordierite.—Cordierite appears to result in the xenoliths, either from the complete solution of aluminous material by a tholeiite-magma, whereby a cordierite-buchite[2] or cordierite-sillimanite-buchite is formed; or from the reaction of the magma with the

[1] 'Notes on the Formation of certain Rock-forming Minerals in & about Glass-Furnaces' Trans. Soc. Glass Technology, vol. ii (1918) p. 177.

[2] For a description of cordierite-buchites, see J. S. Flett, 'Geology of Colonsay, Oronsay, & part of the Ross of Mull' Mem. Geol. Surv. 1911, pp. 94, 95; Prof. A. Lacroix, *op. jam cit.* p. 21, comments on the remarkable sharpness of the crystals and the triple twinning of the cordierite in rocks of this nature; see also J. J. H. Teall, 'The Natural History of Cordierite & its Associates' Proc. Geol. Assoc. vol. xvi (1899) p. 61, with Bibliography on p. 74.

still fluid matrix of a sillimanite-buchite which gives rise to cordierite and spinel, or cordierite and corundum, according to the amount of available magmatic magnesia (see analyses, p. 236).

In the former case of direct and complete absorption of aluminous material by the magma, the cordierites formed are either colourless, rectangular, single crystals with distinct outline, or small triple and complex twins. In magma contaminated with aluminous xenolithic matter, the percentage of alumina may vary within widely-separated limits, and there may be no excess of alumina beyond that necessary to form cordierite with the available magnesia and silica. The result, in such a case, is the formation of a cordierite-buchite that consists solely of cordierite and brown glass (Pl. VII, fig. 3). Such cordierite must be regarded as of pyrogenetic, rather than of metamorphic, origin. When there is a greater proportion of xenolithic matter, sillimanite is the earlier product of crystallization, and this is followed by cordierite, giving rise to a cordierite-sillimanite-buchite similar to that figured in Pl. VII, fig. 2. The formation of cordierite under such conditions has been dealt with and described by many authors.

When the tholeiite-magma reacts upon an already-formed sillimanite-buchite, bringing about mutual modification by the transference of alumina from the xenolith to the magma, and of magnesia from the magma to the xenolith, large crystals of cordierite grow outwards from the magmatic side into the buchite, keeping pace with the diffusion of magnesia. Much of the sillimanite of the buchite is generally resorbed, but such cordierite-crystals commonly enclose a considerable undissolved portion in the form of the usual slender needles. These needles are often to be seen passing across the boundary between cordierite-crystals and buchite (Pl. X, fig. 1).

Material collected from Locality 6, 3500 feet north of west of Ormsaig, shows beautifully the result of interaction between sillimanite-buchite and magma, and is illustrated by figs. 2 & 3 of Pl. X. The sillimanite-buchite may be seen to pass, in the direction of the igneous rock, into a sillimanite-cordierite-buchite of somewhat coarsely crystalline character, the relatively large size of the crystals being attributable to sustained elevated temperature. Adjoining the true sillimanite-buchite the cordierites are of large size, and, owing to their remoteness from the source of magnesia, contain no inclusions of spinel; but nearer the magma, where more magnesia and less silica were available, the cordierites are full of minute brownish-green crystals of spinel (Pl. VII, fig. 4).

As is occasionally the case with cordierite of a pyrogenetic nature, the mineral is colourless, exhibits no pleochroism, and in no instance shows pleochroic halos around inclusions such as are usual in the cordierite of the crystalline schists and metamorphic rocks. The formation of cordierite in the xenoliths appears in all cases to belong to a relatively late stage in their metamorphism, and to be the natural product of a magma that had become relatively richer in silica by the normal process of differentiation, acting on highly-aluminous material such as the sillimanite-buchite. The proportion

of the cordierite so formed to spinel is determined by the relative amounts of magnesia and silica available. If there be an excess of silica, cordierite would form alone; but, with a deficiency in silica, spinel would be its necessary companion.[1]

Spinel.—The spinellids of the xenoliths, taken collectively, present a considerable variety of colour and, presumably, of composition; but, considered in connexion with their respectively-associated minerals, they show a fair amount of consistency. The chief mode of occurrence of spinel is as a deep-green variety (hercynite-pleonaste), in intimate association with anorthite in the external crystalline zone of the xenoliths. The manner of association of these two minerals indicates contemporaneous crystal-growth, with a gradual convergence towards eutectic composition. Such a condition appears to have been actually realized in some instances under special conditions, and a highly characteristic structure has resulted (Pl. VIII, fig. 5). In this association the spinel is usually without well-defined crystalline boundaries, and its form is almost exactly similar to that assumed by olivine, when associated with anorthite in such rocks as the allivalites of Dr. A. Harker.[2]

It has presumably been formed through the solution of sillimanite and an excess of alumina of the sillimanite-buchite by a magma locally enriched with lime, ferrous iron, and, to a less extent, magnesia. An analysis of this early-formed leek-green spinel, separated from the anorthite-corundum-spinel assemblage of a xenolith from Locality 2, is given below, and indicates a variety lying between the magnesian pleonaste and the ferrous hercynite.

Analysis of Dark-Green Spinel from Xenolith (Anal. III, p. 236), Nuns' Pass, by E. G. Radley.

	I.	II.
	Per cent.	Per cent.
SiO_2	0·77	—
TiO_2	0·50	—
Al_2O_3	60·84	61·70
Fe_2O_3	4·26	4·32
FeO	24·00	24·34
MnO	0·15	0·15
CaO	0·36	0·36
MgO	9·37	9·50
H_2O above 105° C.	0·14	—
Totals	100·39	100·37

The figures given in the second column are derived from those of the first by recalculation, after rejecting silica, titanic oxide, and water, which are regarded as non-essential constituents. See 'Summary of Progress for 1913' Mem. Geol. Surv. 1914, pp. 80, 81.

A very beautiful relation between spinel and anorthite may

[1] G. A. F. Molengraaff, 'Cordierit in einem Eruptivgestein aus Südafrika' Neues Jahrb. vol. i (1894) p. 79; see also J. Morozewicz, 'Experimentelle Untersuchungen über die Bildung der Minerale im Magma' Tscherm. Min. Petr. Mitt. vol. xviii (1898–99) pp. 56, 57.

[2] 'The Natural History of Igneous Rocks' 1909, fig. 49, p. 170.

be studied in specimens from Locality 16, figured in Pl. VIII, figs. 3 & 4. Here spinel-crystals, separated from a glassy base, have acted as nuclei upon which have grown crystals of anorthite, in such a manner as completely to surround the spinel with an irregular but thin zone of this mineral. This relationship existing between spinel and anorthite is one of the most striking features of the xenoliths, and is easily explicable in the light of work recently carried out on the ternary system anorthite-forsterite-silica.[1]

As a much darker variety (black, brown, or dark plum-colour), spinel builds regular well-shaped octahedra in the outer and most highly-modified portions of the xenoliths. There is good reason to believe, from the microscopic evidence, that these spinels result from a later interaction of magmatic and xenolithic material, whereby the already-formed anorthite that contained sillimanite has been resorbed by a magma relatively rich in magnesia; and that the excess of alumina so provided has been precipitated as spinel, accompanied by the separation of a sillimanite-free less basic plagioclase (oligoclase) and glass of magmatic nature. Sillimanite-bearing anorthite in all stages of dissolution, and the separation of spinel together with the formation of less basic felspars, are features illustrated by several examples in Plates IX & X. The sharply idiomorphic form of the spinel-crystals is well shown in Pl. X, fig. 4 and Pl. VIII, fig. 2. A late conversion of spinel into yellow or green serpentine is not an uncommon feature of the xenoliths. The serpentine either forms a peripheral skin (Pl. IX, fig. 2), or completely replaces the crystal.

(iii) Probable Nature of the Unaltered Xenolithic Material.

The aluminous xenoliths, although complex in mineral contents, and varying considerably in composition in different parts of their mass, are clearly fragments of highly-aluminous shale that have suffered progressive metamorphism by a basic igneous magma.

There is no doubt, from the character and composition of the sillimanite-buchite, that this material has been produced by the simple fusion of aluminous sediment, and that it is unmodified in any way by the transfusion of igneous matter. Its composition is represented by Analysis IV (p. 236), from which it will be seen that it is comparable to a highly aluminous fireclay, and that it is free from all bases such as would be present if contamination by an igneous magma had taken place. Microscopically, it consists of glass in which are embedded, often with clear fluidal arrangement, minute but abundant prisms of sillimanite, an occasional crystal of corundum, and a very small quantity of magnetite or some other spinellid. The original rutile-needles of the sediment appear, in some instances, to be preserved.

The analysis indicates that corundum, separately determined, constitutes about 0·5 per cent. of the whole, and sillimanite

[1] O. Andersen, 'The System Anorthite-Forsterite-Silica' Amer. Jour. Sci. ser. 4, vol. xxxix (1915) p. 407.

18 per cent., the remaining constituents entering into the composition of the glass, which holds a fairly large amount of water in solution. Such rocks are well known from other localities, and are produced artificially every day in glass-pots and furnace-nozzles by the fusion of the aluminous material of which they are constructed.[1]

The uniformity observed in the aluminous xenolithic material makes it clear that we have only one type of aluminous sediment to consider, and that this was in all probability of wide distribution.

One somewhat unusual feature brought out by Mr. Radley's analysis is the excess of soda over potash. In most clays the reverse is the case, but exceptions are not unknown.

(iv) Relation of the Xenoliths to the Enclosing Rock.

A striking feature connected with the xenoliths is the extreme sharpness with which they are marked off from the enclosing rock, and the unmodified character of the igneous rock in contact with them. It is clear without additional evidence that the metamorphism was not effected in place by the igneous magma now represented by the surrounding tholeiite, but was carried out at much greater depths and at a more elevated temperature than that appertaining to the rock at the time of its intrusion.

The most convincing evidence of deep-seated metamorphism, however, is furnished by the fact that the enclosing rock often bears no relation to the various metamorphic zones of the xenoliths, and therefore cannot have produced them. It has been pointed out (p. 241) that these zones are occasionally concentric and roughly spherical in form, more often they occur as crescentic or straight parallel layers ending abruptly at the surface of a xenolith. It is abundantly clear, as we shall see, that these zones are the result of progressive metamorphism, and yet in the portion of the sill that we can study we find the enclosing rock crossing from one metamorphic zone to another—from sillimanite-buchite to the anorthite-sapphire-spinel-layer—without any corresponding change in its texture or composition, or any diminution in the sharpness of the line of junction. No better evidence is needed to prove that the metamorphism of the xenoliths was practically complete before they were carried by the molten igneous rock into their present position.

That the xenoliths were still plastic and partly molten at the time of their intrusion is shown by their often intensely vesicular character. These vesicles occur in the now glassy portion of the xenoliths, and mark the escape of gas from the molten material on the intrusion of the xenolith from a region of high to a region of lower pressure.

Prof. A. Lacroix has pointed out, from his study of xenoliths, that the mutual chemical changes produced by a magma on accidental inclusions and *vice versa* are usually quite limited; and, therefore, he rightly asserts that, in order to produce any considerable effect, a prolonged sojourn of the xenoliths within the molten magma is necessitated.

[1] G. V. Wilson, *op. jam cit.* p. 200; A. H. Cox, 'Notes on some South Staffordshire Fire-clays & their Behaviour on Ignition' Geol. Mag. 1918, p. 59.

(v) The Conditions of Metamorphism.

It is clear that the metamorphism of the aluminous sediment that gave rise to the xenoliths was effected before the intrusion of the sill. Further, it is evident that the xenoliths, as we now find them, owe their main characters to both physical and chemical action on the part of the molten igneous rock, the one producing simple melting without transfusion of material from the magma, the other bringing about a local enrichment of certain bases (lime, ferrous oxide, and magnesia), which resulted in the formation of anorthite, sapphire, and spinel. There is little doubt that the greater part of the metamorphism of the aluminous sediments was actually effected in the walls of the magma-basin, and that the xenoliths are mainly due to the disruption of the metamorphosed lining of the basin preliminary to the intrusion of the magma into its present higher position. Only in this way is it possible to account for the lack of symmetry of the metamorphic zones in the xenoliths and the transgression of the enclosing igneous rock across zones that clearly indicate different phases of metamorphism. A general idea of the process was many years ago clearly outlined by Sir Jethro Teall, who said:—

> 'The subterranean magmas act powerfully on their containing walls, and transform highly argillaceous sediments into crystalline rocks composed of cordierite, sillimanite, biotite, quartz, and sometimes spinelle and corundum. The rocks of the inner contact-zone become shattered, and the igneous magma insinuates itself between the cracks, or may even permeate the mass. Portions of the metamorphic rock float off into the molten material, and travel with it through dykes and other channels to the surface.'[1]

In the cases under description the first change effected in the aluminous sediment was simple fusion forming a viscous melt, from which the excess of alumina was early to separate as corundum and sillimanite. The former exists as small hexagonal plates, the latter as minute elongated prisms. The rapid separation of sillimanite rendered the fused layer still more viscous, and presumably enabled it, without application of external stress, to retain its position as a lining to the magma-basin. Simultaneously, however, the transfusion of bases, more particularly of lime, was proceeding from the magma into the aluminous melt that formed the matrix of the already separated sillimanite. This transfusion produced a melt of such composition that anorthite was capable of crystallization as a primary phase, and, owing to the partial resorption of sillimanite to furnish the necessary silica, there was a simultaneous precipitation of corundum.

The anorthite thus formed enclosed the undissolved sillimanite-needles of the original melt (Pl. VII). Similarly the transfusion of the bases ferrous iron and magnesia gave rise to spinels of various compositions, which occur occasionally intergrown with corundum, and either completely enclosed in anorthite or in approximate eutectic relationship to this mineral.

[1] 'The Natural History of Cordierite & its Associates' Proc. Geol. Assoc. vol. xvi (1899) p. 65.

The relations borne by the corundum, spinel, and anorthite one to the other indicate clearly that a melt was produced at the surface of the aluminous material from which these three minerals crystallized with more or less perfect equilibrium, but in which sillimanite was undergoing slow re-solution. The condition indicated is one of slow cooling.

We are here dealing with the crystallization of a quaternary system subject to constant influx of material by diffusion; but, from the conditions controlling the separation of solid phases in the ternary systems anorthite-forsterite-silica and lime-alumina-silica, we are able to gather reasonable ideas as to the temperature-concentrations that operated in the case of the xenoliths.

Let us consider the probable condition of the magma within its basin. We know from the cognate xenoliths present within the tholeiite, that the magma had commenced to crystallize before its upward intrusion, and that crystals of bytownite and pyroxene (both rhombic and monoclinic) were separating and being segregated under the influence of gravity. The separation of pyroxene and bytownite is what might be expected from a magma of the composition indicated by Analysis II, p. 236. The gabbroic or noritic matter so separated may be considered to have crystallized under conditions of more or less perfect equilibrium, without considerable under-cooling, and thus a temperature of initial crystallization between 1200° and 1300° C. is indicated.[1]

We have a useful temperature-indicator in tridymite, the only phase of silica that existed as a metamorphic product, either in the xenoliths or in the Carsaig Sandstone in contact with the intruded sill. The absence of cristobalite and presence of tridymite in both instances would suggest that the temperature of the magma within its basin and at the time of its intrusion was lower than 1470° C.

Except for the presence of tridymite in the siliceous xenoliths, we have little to guide us in an estimation of the initial temperature of the magma within its basin; but from the strong evidence that fusion of the basin-walls proceeded more rapidly than the co-solution of the aluminous melt and magma, we may infer that the magmatic temperature was at any rate above that necessary to vitrify aluminous sediments. Such a temperature has been proved by experiment,[2] in the case of dry melts at atmospheric pressure, to be in the neighbourhood of 1500° C. The retention of much water, however, as well as the presence of small quantities of fluxes, would undoubtedly lower the temperature of vitrification considerably, probably below 1400° C. We are, therefore, fairly safe in regarding the metamorphism of the xenolithic material as commencing at a temperature above, but not far above, that which marked the separation of the cognate xenolithic material from the

[1] G. A. Rankin, 'The Ternary System $CaO–Al_2O_3–SiO_2$' Amer. Jour. Sci. ser. 4, vol. xxxix (1915) p. 1; O. Andersen, 'The System Anorthite-Forsterite-Silica' *ibid.* p. 407.

[2] A. H. Cox, Geol. Mag. 1918, p. 59.

magma, and probably continuing up to the time of the magma's intrusion into higher levels.

The vitrification of the aluminous 'bank' was followed almost at once by the separation of corundum and sillimanite from the aluminous melt and, contemporaneously, a narrow diffusion-band of hybrid character was formed between the normal magma and the fused lining of the basin. Across the junction of sediment and magma the following zones would appear to have been present:—

(*a*) Unfused aluminous sediment; (*b*) fused sediment from which sillimanite and some corundum has separated; (*c*) a zone of commingling of the aluminous melt with the magma; and (*d*) the magma in an unmodified condition.

It is the hybrid zone (*c*) that gives to the xenoliths their most remarkable character. The liquid formed by the commingling of aluminous melt and magma was of such a composition that corundum, anorthite, and spinel were, relatively speaking, insoluble, and were early phases of crystallization, and that the sillimanite of zone (*b*) was unstable and tended to dissolve.

Corundum and spinel have often crystallized together, and there is evidence of the attainment of eutectic relations between anorthite and spinel. Corundum was in most cases the primary phase, and was followed rapidly by the separation of anorthite and spinel, as the composition of the melt changed with continued crystallization.

According to the work of Rankin, the temperature at which anorthite, corundum, and sillimanite can co-exist in equilibrium with the melt is represented by a quintuple point on the ternary diagram of the system $CaO–Al_2O_3–SiO_2$, and corresponds to a temperature of 1512° C. In the xenoliths, however, this condition does not appear to have been attained, for sillimanite was evidently undergoing solution during the formation of the anorthite. The actual conditions of temperature and concentration, therefore, are more probably represented by some point on the boundary-curve between the corundum- and anorthite-fields and away from the quintuple point. The temperatures along this boundary-curve range from 1500° to 1380° C., generally lower than that of the quintuple point, and suggest that the separation of corundum and anorthite took place at a less elevated temperature.

Confirmation of a lower temperature is also furnished by the mutual relations observed to exist between corundum and spinel. Their obviously contemporaneous and early separation from the melt would indicate some such conditions as those expressed by the boundary-curve between the corundum- and spinel-fields in the diagram for the ternary system anorthite-forsterite-silica, and covering a range of temperatures from 1450° to 1325° C. Again, we have the observed eutectic relation of anorthite to spinel. From the work of Olaf Andersen we learn that with relatively small percentages of magnesia, anorthite and spinel can co-exist in equilibrium with the melt at a temperature as low as 1440° C.

All the evidence, therefore, so far as it can be co-ordinated,

points to a maximum temperature in the neighbourhood of 1400° C. as that at which the formation of the xenolithic minerals was likely to have taken place. We must remember, however, that all the work that has been done on the various ternary systems has been carried out at atmospheric pressure and under anhydrous conditions. In the case of the xenoliths we are, in the first place, not dealing with pure ternary mixtures, but with melts containing a far greater number of components the presence of which will undoubtedly depress the freezing-points of the various solid phases. Operating in the same direction will be the large amount of water held in solution at the high pressure obtaining within the magma-basin. It is fairly certain, therefore, that the probable temperatures of separation of the various crystalline phases that occur in the xenoliths, were lower than those judged to have existed in analogous but not identical anhydrous melts. How much lower the present state of our knowledge leaves an open question.

So soon as crystallization commenced in the hybrid zone (*c*) we must assume that transfusion of the components entering into the composition of the separating phases began, and was continued as fast, and for as long a period as the viscosity of the melt and magma would allow. That this diffusion accompanying crystallization was a factor of considerable importance will be seen at once on comparing the analyses of tholeiite (II), hybrid zone (III), and buchite (IV), given on p. 236. From these it is obvious that the ultimate composition of the hybrid zone could not be reached by simple mixture of fused aluminous sediment with tholeiite-magma, but only by the selective diffusion of their respective component oxides. While Analysis III (p. 236) represents a particular phase of interaction between tholeiite and fused aluminous sediment, the reader is warned against regarding it as expressing the composition of a simple mixture. The normal crystallized zone consists of anorthite, corundum, and spinel, and clearly indicates diffusion of alumina from the sediment and of lime, and to a less extent of ferrous oxide and magnesia, from the tholeiite. There has also been a relative concentration of alkalies.

Anorthite being an early and dominant phase to separate from the melt represented by the hybrid zone, it follows that the magma in the immediate neighbourhood would be impoverished as regards lime and relatively enriched as regards magnesia, iron, and alkalies. The slower transfusion of magnesia makes itself evident in the precipitation of spinel, more particularly in that portion of the hybrid zone which lies nearest to the magma. The extent of such an impoverished zone would depend on the viscosity of the melt, and thereby the extent to which diffusion could operate. We have every reason to believe that this zone was not wide, and that, for all practical purposes, we may regard the bulk of the magma within the basin as unmodified by loss of bases or by the assimilation of sedimentary material.

We now come to another and obviously later phase of metamorphism that has been superinduced upon the buchite (*b*) and the crystalline zone (*c*). Disruption of the already crystallized anorthite-corundum-spinel assemblage of the hybrid zone, by stresses acting within the basin prior to the upward intrusion of the magma, allowed the locally-modified magma mentioned above to make fresh contacts with the buchite, and with the more aluminous portion of the anorthite-corundum-spinel zone adhering to the walls of the magma-basin. This partial magma being relatively rich in magnesia, iron, and alkalies, the new contacts resulted in a fresh set of concentrations. Cordierite (p. 245) under the new conditions was one of the chief crystalline substances to separate out; while the rapid enrichment of the melt by alumina from the resorbed sillimanite, taken in conjunction with the excess of magnesia beyond that required for the formation of cordierite, produced an almost simultaneous precipitation of corundum and spinel. The melt, being of a more alkaline character than previously, caused the resorption of much of the early-formed anorthite, and only permitted the subsequent separation of a plagioclase of increased alkalinity (p. 245).

Reviewing the temperature-conditions, as suggested by the crystalline phases of the accidental and cognate xenoliths, we are led to the conclusion that the temperature-interval during which the metamorphism of the aluminous material was accomplished was small, and probably lay between 1400° and 1250° C. On the other hand, the time interval was great, for extremely slow cooling and no considerable change in the viscosity of the melt are indicated.

Towards the end of this period, a limit only imposed by the upward intrusion of the magma, that magma had commenced to crystallize on its own account, with the formation of the cognate xenoliths at a temperature that did not exceed 1300° C., and was probably still lower. At the time of upward intrusion the temperature was sufficient to keep molten the glassy matrix of the sillimanite-buchite, and to produce tridymite-fringes upon the quartz-grains of the Carsaig Sandstone.

Experiments on the glassy matrix of the sillimanite-buchite prove that it melts at a temperature near that of fluorspar (1250° C.), so that we may suggest that the temperature of the magma at the time of its intrusion approximated to this value.

It will be seen from the above that the probable range of temperature covering the metamorphic processes that operated within the basin, and the subsequent upward intrusion of the magma, is surprisingly small, possibly less than 200° C.

At the time of upward intrusion all further transfusive action between magma and xenoliths would be checked by rapid cooling, and this would account for the sharp boundaries presented by the xenoliths to the surrounding tholeiite.

V. Summary and Conclusions.

The western portion of Mull lying between Loch Scridain and Loch Buie is remarkable for a series of minor intrusions that are generally of a tholeiitic and andesitic character. Occasionally they are composite, and one of the best examples of such a sill is that which occurs at Rudh' a'Chromain and at Nuns' Pass west of Carsaig. They frequently contain abundant xenoliths of both accidental and cognate nature. The cognate xenoliths are glomero-porphyritic masses of bytownite and hypersthene, or bytownite and augite, and are frequently congregated in the lower portions of the intrusions. The accidental xenoliths are both of siliceous and aluminous types, the aluminous inclusions being generally by far the more prevalent and ranging up to several feet in diameter. The siliceous xenoliths show the usual type of alteration: quartz-grains have developed fringes of tridymite, and in some instances are surrounded by secondary augite. The aluminous xenoliths, with which this paper deals more particularly, are characterized by well-crystallized minerals, such as corundum (sapphire), spinel, sillimanite, cordierite, and anorthite.

These aluminous xenoliths offer the clearest evidence of the modification of a more or less pure aluminous sediment by permeation of magmatic matter, more particularly by the diffusion of lime, ferrous iron, and magnesia. The aluminous sediment, when simply altered by thermal agencies, takes the form of a sillimanite-buchite (sillimanite and glass), and this by the chemical action of the magma has most often been transformed, in whole or in part, into a coarsely-crystalline mass of anorthite that encloses sillimanite, corundum, and spinel. Further action by the magma in a modified form, in which it is relatively enriched by magnesia and alkalies, has resulted in the formation of cordierite with a concomitant separation of corundum, spinel, and an acid plagioclase.

It is held from the evidence afforded by the xenoliths that the metamorphism was of a deep-seated character, and was produced by a tholeiitic magma acting upon the lining of its basin, this lining being constructed largely of aluminous sedimentary material. The deep-seated character of the metamorphism is supported by three facts:—(1) the xenoliths show practically no signs of modifying, or of modification by, the igneous rock now in contact with them; (2) during the process of intrusion into their present position they have suffered deformation, owing to their still plastic state; and (3) they have developed vesicular cavities in their contained glassy matter, consequent on the decrease of pressure by which dissolved volatile constituents were allowed to escape. The vesicular cavities have in many instances been filled with low-temperature minerals such as analcite, chalcedony, and calcite. The mutual relations of the various xenolithic minerals, interpreted in the light of recent work on fused mixtures of silicates and oxides, suggest that the temperature of the magma in its basin during the period in which the metamorphism was effected probably

ranged from near 1400° to 1250° C., the lower temperature approximating to that at which the magma, together with its xenoliths, was intruded into its present position.

There is practically no evidence such as would lead to the conclusion that the magma as a whole has been modified to any extent by assimilation of sedimentary material, despite the fact that certain intrusions consist almost entirely of xenolithic matter.

EXPLANATION OF PLATES VI–X.

[The numerals preceded by S are the registration-numbers of the respective rock-slices in the collections of the Geological Survey.]

I am indebted to Mr. John Rhodes for the preparation of the photomicrographs which are reproduced in these plates.

Plate VI.

Fig. 1. Glassy acid interior of a composite sill, Rudh' a'Chromain. Rhyolite allied to inninmorite. Blade-like and acicular crystals of augite and small porphyritic crystals of acid labradorite in a pale lavender-brown glassy matrix. Local devitrification has given rise to patches of acid labradorite, showing white in the figure. S. 18486. × 16·5. (See p. 235.)

2. Acid interior of a composite sill, Rudh' a'Chromain, more or less completely devitrified. The more complete devitrification has caused the separation of less basic plagioclase, together with some orthoclase and quartz. S. 18488. × 18. (See p. 235.)

3. Tholeiite. Upper edge of the basic portion of a composite sill, Rudh' a'Chromain. Narrow lath-shaped crystals of labradorite and chloritized augite, in a brown glassy matrix charged with magnetite. S. 18480. × 18. (See p. 235.)

4. Tholeiite. Basic stony portion of a composite sill, Rudh' a'Chromain, showing the characteristic structure assumed by these rocks. The constituents are labradorite and hypidiomorphic augite, with a relatively small amount of residual glass. S. 18490. × 18. (See p. 235.)

5. Cognate xenolith, in the lower basic portion of a composite sill, Rudh' a'Chromain. The xenolith consists of glomeroporphyritic bytownite and greenish augite. The enveloping tholeiite is similar to that shown in fig. 4. S. 17173. × 15·5. (See p. 238.)

6. Cognate xenolith, in the lower basic portion of a composite sill, Rudh' a'Chromain. The xenolith consists of bytownite and hypersthene. The hypersthene is sharply idiomorphic and intensely pleochroic. The felspars are idiomorphic, of large size, moulded on the hypersthene, and their composition is that of basic labradorite or bytownite. S. 16598. × 18. (See p. 238.)

Plate VII.

Accidental Xenoliths.

Fig. 1. Sillimanite-buchite, 3500 feet north of west of Ormsaig. Needles of pale-pink sillimanite, embedded in clear pale lavender-coloured glass. Distinct fluxion-structure is developed locally. The rock is slightly vesicular, the vesicles being filled with zeolites and calcite, and results from the simple fusion of an aluminous shale. S. 18005. × 36. (See p. 243.)

Fig. 2. Sillimanite-cordierite-buchite, 500 yards north-east of Abhuinn Bail' a'Mhuilinn, 1000 yards north of west of the bridge over Allt a'Mhuchaidh. The rock contains a few large and many small crystals of anorthite, in a glassy matrix that is partly magmatic and felspathic and partly a sillimanite-cordierite-buchite, as figured. The cordierite-crystals are particularly well-formed. The rock suggests the incomplete solution of aluminous shale in a tholeiitic magma. S. 18529. × 131·5. (See p. 245.)

3. Cordierite-buchite, Allt a'Mhuchaidh, 1000 yards above the bridge. Composed of beautifully-formed crystals of cordierite, many showing complex twinning, in a matrix of brown glass. The rock is due to the local solution of aluminous xenolithic material by the tholeiitic magma. S. 17997. × 10. (See p. 245.)

4. Sillimanite-cordierite-buchite, Ormsaig. Large well-formed rose-pink crystals of sillimanite, and crystals of cordierite crowded with minute brownish-green spinels, in a brown glassy matrix. The striking feature of the rock is the size and colour of the sillimanite-crystals: their large size suggests long-continued heating and relatively-slow crystallization. S. 18001 a. × 11. (See p. 245.)

5. Siliceous xenolith of partly dissolved sandstone, Feorlein Cottage, Carsaig. The individual quartz-grains show beautiful tridymite-fringes, now reverted to quartz. Large plates of tridymite, similarly changed, occur in the glassy matrix. S. 20283. × 20. (See p. 240.)

6. Siliceous xenolith, south-east of Gortein Driseach. The quartz has undergone resorption by a melt of mixed character that has consolidated as a streaky glass. Tridymite-fringes occur around the quartz-grains, and cordierite is to a small extent developed in the matrix. The rock has been produced by the action of a tholeiitic magma on a quartzite. S. 16067. × 11. (See p. 239.)

Plate VIII.

Fig. 1. Small crystals of anorthite, showing evidence of rapid growth, forming in a glassy magmatic matrix. They are the result of reaction between the magma and an aluminous xenolith, and are accompanied by spinel. Allt a'Mhuchaidh. S. 17998 a. × 15. (See p. 244.)

2. Anorthite-sapphire-spinel assemblage. The normal crystalline aggregate that appears to result from the initial action of the tholeiite-magma on an aluminous xenolith. S. 16611. × 12·5. (See p. 240.)

3. This shows the crystallization of sapphire and deep-green spinel in brown magmatic glass. Both minerals are separated from the glass by zones of anorthite-crystals. The manner in which the crystals of anorthite are planted upon the spinels is particularly striking; see also fig. 4. Allt a'Mhuchaidh, 1000 yards above the bridge. S. 17999. × 7. (See p. 247.)

4. Another portion of the same section with higher magnification. Note the well-formed crystals of anorthite growing in brown glass, and planted on an elongated crystal of greenish-brown spinel. The spinel is possibly pseudomorphous after sillimanite. S. 17999. × 42. (See p. 247.)

5. Anorthite-spinel assemblage of an aluminous xenolith, showing green spinel and anorthite in eutectic relationship. The structure probably results from the reheating of the ordinary spinel-anorthite aggregate of an aluminous xenolith—a point emphasized by the occurrence of pseudomorphs after cordierite within the anorthite of another part of the slide. Old Road, 100 yards north-west of Feorlein Cottage, Carsaig. S. 20286. × 29. (See p. 247.)

Fig. 6. Aluminous xenolith, showing anorthite full of minute crystals of corundum and invaded by magma. The magma has resorbed part of the original felspar with its excess of alumina, bringing about the growth of a less basic felspar in optic continuity with that previously existing, and the precipitation of well-formed plum-coloured spinels. A large crystal of spinel occupies the centre of the field. Rudh' a'Chromain. S. 16605. × 12. (See p. 245.)

Plate IX.

Fig. 1. Xenolith invaded by tholeiitic magma. The mass consists of anorthite full of sillimanite-needles which have been partly re-dissolved, with the subsequent growth of secondary felspar on the remaining anorthite. The later felspar is free from sillimanite, and consists partly of anorthite, partly of oligoclase, which forms the outermost zone and sends skeleton growths out into the glassy matrix. The later formation of the felspar of more acid character has been accompanied by the precipitation of the excess of alumina as sapphire and spinel. The sapphires (of which several are shown in the figure) are surrounded by feathery growths of oligoclase. Rudh' a'Chromain. S. 17177. × 13·5. (See p. 245.)

2. Xenolith invaded by tholeiitic magma. The section shows anorthite full of sillimanite, and a sillimanite-buchite invaded by dark tholeiitic matter (glass). Resorption of anorthite with its contained sillimanite has taken place, followed by the crystallization of large dark-green spinels (and cordierite enclosing spinel). A less basic felspar, following solution of the sillimanite-bearing anorthite, has grown outwards from the undissolved anorthite, and forms a noticeable zone between it and the magmatic glass. Shore a quarter of a mile from the mouth of Allt Coille Moire. S. 17405. × 16. (See p. 247.)

3. Original anorthite of a xenolith full of sillimanite undergoing partial resorption by tholeiitic magma, with the separation of the excess of alumina as corundum and spinel, and the feathery crystallization of a less basic plagioclase (oligoclase) in the matrix. Rudh a'Chromain. S. 17178. × 13·5. (See p. 248.)

4. Junction of normal tholeiite with sillimanite-buchite, showing a reaction-zone: this zone consists of basic plagioclase and cordierite. Cordierite occurs in relatively large crystals growing into the buchite, is enclosed in the anorthite, and forms a narrow band between the anorthite and the tholeiite. A few crystals of cordierite occur within the tholeiite itself near the junction. Old road 100 yards north-west of Feorlein Cottage, Carsaig. S. 20289. × 9. (See p. 245.)

5. Original sillimanite-bearing anorthite invaded and resorbed by magma, with the consequent crystallization of a sillimanite-free felspar of less basic composition on the undissolved nuclei. Rudh' a'Chromain S. 16603. × 45. (See p. 245.)

6. An example of the breaking-up of the primary anorthite-sillimanite xenolith and resorption by magma. The excess of alumina furnished by the resorbed anorthite and sillimanite has been precipitated as a deep plum-coloured spinel and corundum. A regrowth of basic plagioclase edged with oligoclase has taken place on the undissolved felspar-fragments, and shows white in the figure. The melt surrounding the large spinels finally consolidated as oligoclase, skeleton spinels, and glass. Nuns' Pass, Carsaig. S. 20271. × 7. (See p. 254.)

PLATE X.

Fig. 1. Sillimanite-buchite invaded by magma, with the resultant formation of large crystals of cordierite in a dark glassy matrix charged with acicular crystals of felspar, which range from labradorite to oligoclase in composition. The cordierite-crystals contain sillimanite-needles which are identical with those of the buchite, and are evidently the undissolved residue of the same. The sillimanite is pale pink in both cases. Shore 700 yards south-west of Tiroran. S. 18532. × 18. (See p. 246.)

2. Shows the formation of beautiful crystals of cordierite (partly pinitized) as the result of the reaction between the igneous magma and a sillimanite-buchite. The cordierite-crystals are large and well-formed next to the buchite, but smaller and full of spinel nearer to the true igneous rock. Pink sillimanite occurs as in the above cases, and is obviously of earlier formation than the cordierite. Coast 3500 feet slightly north of west of Ormsaig. × 9. (See p. 246.)

3. This rock consists of an aggregate of anorthite-crystals (large colourless area) that contain small sapphires and a plum-coloured spinel. The anorthite has suffered resorption with the subsequent crystallization of labradorite upon its edges. Large cordierite-crystals, free from inclusions and often exhibiting beautiful twin-structure, have developed in the magmatic matrix. One such crystal of cordierite occupies the centre of the field. Slightly north of west of Ormsaig. S. 18003. × 17, crossed nicols. (See p. 246.)

4. Brecciated anorthite-xenolith invaded by magma, with attendant resorption. The part of the section figured shows the result of the resorption of the original xenolith in the precipitation of large, well-shaped, reddish plum-coloured spinel, crystallization of feathery oligoclase-andesine, and the formation of large rectangular crystals of cordierite in a glassy matrix. North of Feorlein Cottage, Carsaig. S. 18493. × 25. (See p. 248.)

5. Edge of a sillimanite-anorthite xenolith acted upon by magma, and showing the regrowth of basic felspar on the resorbed anorthite. Spinel and less basic lath-shaped plagioclase have formed in a glassy matrix. Note the circular form of an amygdale in the upper part of the figure. Rudh' a'Chromain. S. 16601. × 15. (See p. 245.)

6. This shows the brecciation of the primary sillimanite-bearing anorthite, its partial resorption by magma, and the concomitant precipitation of a plum-coloured spinel and oligoclase in a glassy matrix. North of Feorlein Cottage, Carsaig. S. 18492. × 18. (See p. 254.)

DISCUSSION.

Sir JETHRO TEALL said that, so far as he knew, this was the most perfect case of its kind that had ever been described. The paper was evidently of great interest and importance.

Mr. G. BARROW congratulated the Author on the valuable results of his work on the inclusions of sedimentary material caught up in a volcanic magma at a great depth below the surface. The evidence produced by the Author seemed to indicate clearly that the mineralogical changes had been produced at a considerable depth. The Author was fortunate in having to deal with a material that from its composition could only have been a pure shale originally. The distinctive minerals are the same as

those characterizing the higher thermal zones of the Archæan rocks, and occur continuously through belts of considerable breadth and of unknown length. The Author's work thus supports the view now generally entertained that the distinctive minerals in the Archæan rocks are due to deep-seated changes.

Dr. J. W. Evans remarked on the number of important facts disclosed by the Author's communication, and the interesting deductions which he drew from them. It was remarkable that an argillaceous rock should contain as much soda as that found in the buchite, and that the ratio of potash to soda should be increased by the metamorphism due to an igneous rock containing more soda than potash. He thought that the changes described might have taken place at a comparatively-moderate depth.

The Author expressed his gratification at the reception accorded to his paper, and thanked the speakers, especially Sir Jethro Teall, for their kind remarks. As pointed out by Mr. Barrow, he considered himself extremely fortunate in having such beautiful material to work upon. In reply to Dr. Evans he admitted the somewhat unusual alkali-ratio presented by the buchite; but analyses of aluminous sediments show that an excess of soda over potash is occasionally met with, and he would rather regard this as an inherent property of the shale than as a result of metamorphism. With respect to the depth at which the metamorphism of the xenoliths was accomplished, all that could be said was that it took place within the magma-basin and under a pressure sufficient to prevent the expulsion of any constituents in a gaseous form.

7. *A* COMPOSITE SILL *at* NEWTON ABBOT (DEVON). By WILLIAM GEORGE ST. JOHN SHANNON, M.Sc., F.G.S. (Read November 23rd, 1921.)

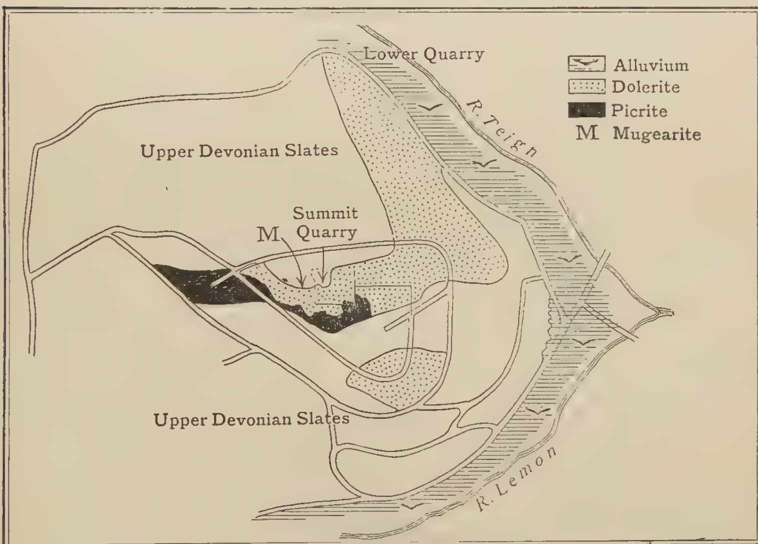
[PLATE XI.]

CONTENTS.

I. INTRODUCTION.

THE sill which is described in this paper forms the summit and part of the northern flank of Knowles Hill, Newton Abbot, 6-inch Ordnance-Survey Map 109, S.E. The hill is bounded on all sides except the western by the alluvium of the Teign and its tributary the Lemon; it forms a prominent hog-back lying in the fork between the two rivers. The base of the hill is formed of Upper Devonian slates, and these are continuous to the west,

Fig. 1.—*Sketch-map of Knowles Hill, Newton Abbot, on the scale of 6 inches to the mile, or 1 : 10,560.*



where, at a distance of about half a mile, another outcrop of dolerite occurs at Highweek Church. The occurrence of picrite was discovered by Busz, and a short description of the sill and of the presence of original quartz is given in the Geological Survey Memoir on the 'Geology of Newton Abbot,' No. 339, 1913.

II. Field Relations.

The summit of Knowles Hill has been quarried, and a smaller quarry exists by the footpath on the north of the hill, bordering the Teign alluvium. The rocks described are mainly from the upper quarry. The northern slopes of the hill are in pasture, and the exposures are too weathered to admit of a petrographic description of the rocks; on the east, the geological lines have been drawn from very limited exposures, as the area has been completely built over. The sill is intrusive into Upper Devonian slates; its lower boundary is indicated by the fact that the floor of the quarry is in slates, the whole of the sill having been quarried away. The upper limit is indicated by the occurrence of spotted slates, the alteration extending for a distance of 6 to 9 inches from the contact; this clearly shows the intrusive nature of the dolerite. The total thickness estimated from these facts gives, at the southern wall of the quarry, only 15 feet; within a distance of 30 yards this has expanded to 30 feet, and the top is not seen, the sill on the north-eastern face becoming more laccolitic in habit. The notable differentiation occurs in the narrow portion. A thin cover of slates separates this upper quarry from a small outcrop on the south-east, and at the edge of the same field on the south-south-west picrite is visible beneath a thin cover of slates. It is probable that the top of the quarry is very little below the upper limit of the sill.

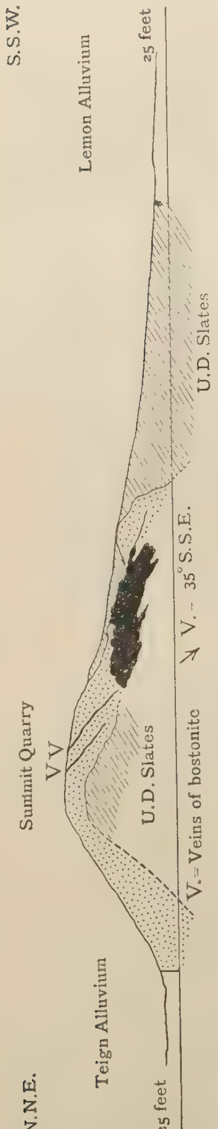


Fig. 2.—*Diagrammatic section across Knowles Hill.*

[Horizontal scale : 12 inches to the mile, or 1 : 5280. Vertical scale exaggerated.]

Some evidence can be obtained for the existence of small thrust-planes or slight faulting:—

(i) The slates on the floor of the quarry are not spotted.

(ii) The slates on the south-west of the quarry abruptly change from purple to black, and are accompanied by a more compact rock which appears to have been a tuff, but has also undergone

contact-alteration; in these rocks there were formerly found excellent large specimens of *Trimerocephalus*. The average dip on the south of the summit is 30° to 35° south-south-eastwards, indicated by the junction of the spotted slates, by the 'bostonite'-vein, and by the inclination of the junction at the floor of the quarry.

In the lower quarry the upper surface dips steeply westwards at 60°, altering the overlying slates, in which *Posidonomya venusta* is found; the lower surface is beneath the Teign alluvium. North of the summit the slope is steep, and it is possible that the dyke-feeder of the sill is here; but no satisfactory evidence could be obtained to decide this point.

III. Macroscopic Characters.

Upper Quarry.—Three rock-types are here in evidence—a dark picrite, ordinary dolerite weathering a rusty brown, and pale veins cutting the dolerite; these are much lighter in colour, and the ferromagnesian minerals are evidently present in but small quantity.

(*a*) The picrite is dark green, with black spots of olivine, and the augite shows slight 'schiller' effect; the rock is hard and remarkably fresh. Its most characteristic feature is the 'xenolithic' structure and a certain amount of veining; the interspaces are occupied by a very decomposed brown material, weathering similarly to the ordinary dolerite. Sections were made, but showed only a structureless chloritic mass. The brecciated appearance is due to these xenoliths, and the occurrence is very similar to that described by Dr. A. Harker from the Skye peridotites; the later doleritic magma has partly resorbed the picrite, further proof of which will be found in the discussion of the xenoliths in the dolerite.

A larger, greyish vein is formed of a decomposed clayey material with fibres of tremolite; this has also broken down, and a few fibres only can be extracted whole. The exact relations of this vein cannot be ascertained, as it disappears vertically downwards; its formation may be due to subsequent movement along a doleritic vein in connexion with the slight thrusting already mentioned or during the injection of the 'bostonite'-vein; tremolite is found in the picrite, but as an alteration-product of the augite.

(*b*) Xenoliths in the dolerite.—The picrite thins out rapidly, and here the rock has been quarried for a few feet more nearly along the strike; but picrite is not visible. The dolerite weathers uniformly, except for some isolated patches from which the crust is easily removed, exposing a hard centre. At first sight, this appears to be due to spheroidal weathering, but the junction is fairly sharp, and microscopic examination confirms the presence of xenoliths; they appear to be restricted to a zone in close association with the salic vein. It will be seen later that these

are cognate xenoliths obtained from the picrite, and have been partly absorbed and carried forward by the dolerite intrusion.

(*c*) Vein of salic facies: 'bostonite.'—A conspicuous feature is the white vein dipping 35° south-south-eastwards, in the same direction as the jointing of the dolerite—its weathered surface is of a light buff colour. In the upper right-hand portion a much thinner band is just visible; this has weathered to a darker colour. The veins are strongly jointed perpendicularly to their surface, giving a partly columnar effect. The fresh rock is bluish grey and felsitic in appearance. There are no noticeable contact-effects, and the vein is sharply marked off from the surrounding rock; but the latter is so decomposed for over a foot below the surface that no sections could be cut to determine the exact contact. That the vein is later than the dolerite is inferred from the columnar jointing and the sharpness of the contact. Both veins dip beneath the quarry-floor, and cannot be proved to cut the picrite.

(*d*) Fine-grained modification of the dolerite.—In the south-western portion of the quarry the wall is low, and a portion about a foot below the top is noticeably less weathered, of greener colour and finer grain. This merges imperceptibly into the ordinary dolerite. Within a few feet, on apparently the same horizon, the dolerite is coarse-grained. This fine-grained rock will be defined as the 'mugearite' modification.

(*e*) The dolerite which forms the bulk of the intrusion calls for no detailed description, its chief characteristic being the facility with which it weathers to a rusty-brown 'wacke.'

(*f*) Lower Quarry.—The rock here is uniform and more compact than the dolerite from the upper quarry. It is of a predominant green colour, much veined by calcite. So far as I have examined it, the picrite or salic veins do not occur, the rock being dolerite throughout. The slates at the contact are altered to a depth of 2 or 3 inches only, as in many dyke occurrences.

IV. Petrography.

(*a*) The picrites.—In hand-specimens these are dark-green rocks, with black patches of olivine and augite showing slight schillerization. In thin section the most notable constituent is olivine in subhedral crystals and smaller grains, the smaller olivines being partly enclosed in poikilitic augite-plates.

The olivine is optically positive, with an angle in air of about 70°, indicating that it belongs to the forsterite end of the series. Its alteration-products are characteristic of the olivines of plutonic rocks: at first a heavy border of magnetite appears; this gradually extends into the interior, forming magnetite dendroids, and the crystal becomes completely veined by magnetite; later this is re-sorbed in the formation of serpentine and calcite. The augite is purplish, and is probably a titan-augite, as in the augite of the essexites; it gives extinction-angles up to 35° or 40°. The augite

alters to a pale hornblende giving extinctions of 15°, and low yellows of the first order: this is referable to tremolite; accompanying this is a similar hornblende giving straight extinctions and more fibrous with rather less colour, probably anthophyllite. Another colourless augite occurs as subhedral crystals with straight extinction, accompanying the larger olivines; it is positive and without pleochroism, exhibiting the characters of an enstatite.

The biotite occurs in strongly coloured red-brown laths, a few of which are partly bleached to a pale crimson-brown; it is biaxial with a small angle, and pleochroic in dark chestnut-brown.

The felspar varies in amount, some of the rock approaching the peridotites; it gives extinction-angles in the few symmetrical sections observed up to 30°, indicating a basic labradorite. Much of it is strongly zoned, and some of the felspar ground is probably nearer anorthite. Apatite occurs in short blunt prisms. The iron-ore is always opaque, and the presence of chromite or any other spinel has not been established. Serpentine after olivine forms about 10 per cent. of the rock.

A Rosiwal analysis of a section was undertaken, and is compared with an analysis by Busz:—

	I.	II.
SiO_2	40·12	40·24
Al_2O_3	7·76	9·59
FeO	16·01	17·94
MgO	23·69	22·04
CaO	6·53	7·20
Na_2O	1·20	1·23
K_2O	0·53	0·50
H_2O	4·03	—
TiO_2	0·37	—
P_2O_5	0·18	—
	100·42	98·74

Specific gravities = 2·96 and 2·97.

I. Picrite, Knowles Hill, Newton Abbot. Busz. (Partial analysis.)[1]
II. Do. do. do. do. do. Rosiwal analysis.

(*b*) Xenoliths in the dolerite.—Slides from the outer parts of the xenoliths show nearly the normal character of the dolerite. The augite is subophitic; occasionally it may be subhedral, and is not quite fresh. Some small tracts of chlorite or serpentine are referable to olivine; the felspar is andesine, giving extinction-angles up to 20°.

Slides from the central parts show a much greater proportion of ferromagnesian minerals. The augite is in part poikilitic to the smaller olivine-pseudomorphs; in general it is subophitic. In Pl. XI, fig. 1 is seen a large pseudomorph after olivine, mainly serpentine with some residual magnetite. A hornblende with very pale-green pleochroism is secondary after either augite or the

[1] Quoted by J. P. Iddings, 'Igneous Rocks' vol. ii (1913) p. 337.

serpentine; it is nearer actinolite than tremolite. The specific gravity=2·85.

(*c*) Bostonite-veins.—In hand-specimen these are bluish grey in the fresh rock and felspathic in appearance. In thin section the rhombs of plagioclase are conspicuous. This is of two kinds: one with albite-lamellæ well developed, and the other with the peculiar streaky appearance of soda-orthoclase. All gradations can be followed, from coarse chequer-structure to the finest microcline; often there is a central chequer-crystal surrounded by chlorite, in turn surrounded by a newer growth of soda-orthoclase. The chequer-structure indicates an albite; but a Becke determination of the refractive index shows that this is higher than in albite, being slightly above that of the balsam of the slide.

Extinctions are not easily measured, but appear to be nearly straight; probably the felspar is referable to potash-soda-oligoclase-albite. A fair amount of orthoclase occurs in anhedral grains.

Chlorite occurs between the crystals, as well as inclusions. Prehnite is an alteration-product of the felspar; there are also a few small grains of epidote, and tremolite in outer portions.

The rock approaches nearly to the salic variety of the albite-dolerite of Trusham as regards the felspars; it approaches the bostonites from the point of view of the scarcity of the ferromagnesian minerals. The following Rosiwal analysis is compared with these rocks:—

	I.	II.	III.
SiO_2	53·59	52·00	58·47
Al_2O_3	17·80	18·06	16·11
FeO & Fe_2O_3	11·82	7·32	7·75
MgO	2·44	2·84	1·58
CaO	1·34	4·59	0·94
K_2O	} 9·82	4·68	5·18
Na_2O		3·78	4·34
Totals	96·81	93·27	94·37

Specific gravity = 2·66.

I. Bostonite-vein, Knowles Hill. Rosiwal analysis.

II. Bostonite, Onston Ness, Orkneys.[1]

III. Albite-diabase, felspathic variety, Trusham.[2] E. G. Radley.

In I, 46 per cent. albite was calculated as Ab_6An_1 22 per cent., soda-orthoclase as 17 per cent. Na + K, and 7·5 per cent. orthoclase, the felspar totalling 76·6 per cent. of the rock. An analysis was conducted on the same rock by means of a Harada-Brögger tube and the felspar separated by the Sonstadt solution; the felspar and the heavy minerals were weighed, about 2 grammes of powder

[1] Quoted by Dr. F. H. Hatch, 'The Petrology of the Igneous Rocks' 1914, p. 240.

[2] 'Geology of the Country around Newton Abbot' Mem. Geol. Surv. 1913, p. 62. (Both analyses are modified.)

being used: this gave a reading of 72 per cent. for the felspar, agreeing fairly closely with the Rosiwal analysis.

(*d*) Fine-grained dolerite ('mugearite' variation).—In thin section the plagioclase-laths give a trachytic aspect to the section, and the extinction is sensibly straight; the average length of these laths is about 1·5 mm. The plagioclase is not all of one kind; in addition to these, more tabular felspars and some interstitial grains of unstriated felspar referable to orthoclase occur. In one case this could be established by a Becke test, giving a refractive index lower than that of balsam. The tabular crystals give extinction-angles up to 12° or 14°, and are evidently oligoclase-andesine, the refractive index being equal to that of quartz. The lath-felspars form about 35 per cent. of the rock; their refractive index is below that of quartz, and with the straight extinction this indicates oligoclase. In addition to these, a few rhombs are seen presenting the streaky appearance of soda-orthoclase. A fair amount of chlorite occurs, but no fresh augite; in some cases the chlorite may be after small olivine. The final product of crystallization is quartz moulding some of the felspar, and containing small elongated needles of apatite: hence this is primary. Larger quartz-grains occur, notably corroded, with inlets of the ground and with a border of granular chlorite; this is xenolithic quartz. Calcite is present in grains. The iron-ore appears to be always magnetite.

The rock presents considerable affinities to the mugearites, as defined by Dr. A. Harker. A partial Rosiwal analysis is compared with the percentages given by him[1]:—

I.	Per cent.	II.	Per cent.
Oligoclase	37·53	Oligoclase	57·5
Oligoclase-andesine	11·04		
Orthoclase	5·71	Orthoclase	12·5
Quartz	0·81		
Chlorite	35·51	Olivine, etc.	26·5
Magnetite	9·38	Apatite	3·5
Totals	99·98		100·00

Specific gravity = 2·76. Specific gravity = 2·79.

I. 'Mugearite' variation of dolerite, Knowles Hill. Rosiwal analysis.

II. Mugearite, Druim na Criche (Skye).

The lower specific gravity is probably due to secondary alteration. The Knowles-Hill rock is more basic, and analcite was not found, although carefully searched for; the texture is also coarser.

(*e*) Dolerite.—The sections of dolerite display no especial features beyond the occurrence of quartz, both original and xenolithic. They are not very fresh, even at some distance from the surface. The augite is usually ophitic to subophitic, but in some

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 265.

of the slides (N 20)[1] there are two generations, smaller crystals which are euhedral and showing diallage striation, and a later ophitic generation: in N 18 the augite is ophitic throughout. The plagioclase is of an acid variety, giving extinction-angles in symmetrical sections up to 15°, with a refractive index higher than quartz, and is referable to andesine; in N 15 this is acid, in N 18 it becomes more basic. Orthoclase appears to be present in most of the slides—in N 15 it forms about a third of the felspar, showing gradation towards a monzonite facies.

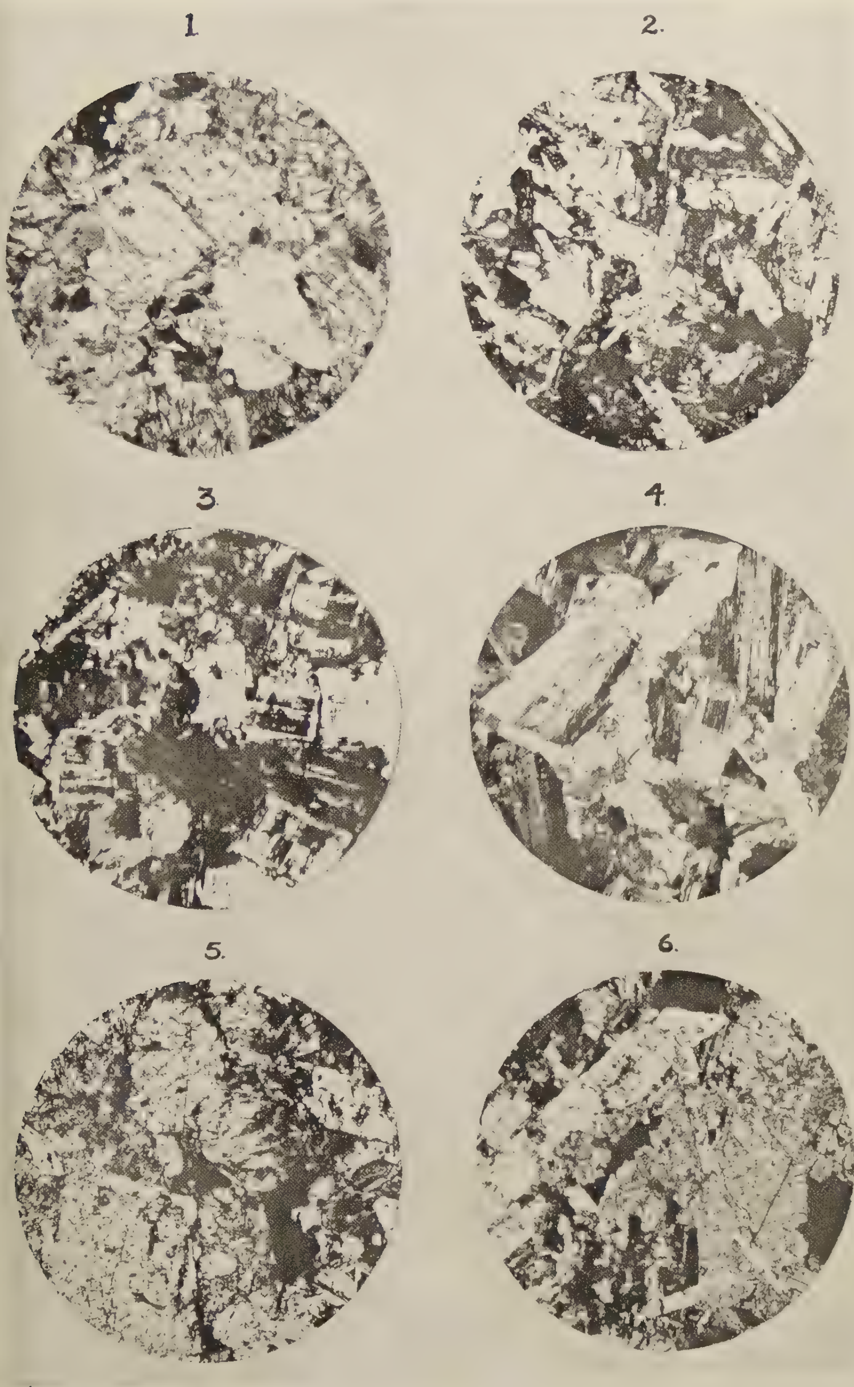
Accessory minerals are quartz, iron-ores, and apatite. The bigger grains of quartz show corrosion-borders with granular epidote or chlorite, and deep inlets occupied by chlorite; the smaller grains are anhedral to the felspar, and contain prisms of apatite of the same size as in the normal rock. The amount of the quartz varies, in some cases amounting to at least 3 per cent. The iron-ore may be either ilmenite or pyrites, rarely magnetite. Secondary minerals are epidote in considerable quantity after felspar, and chlorite after augite. The texture is generally rather fine-grained, becoming coarser with the occurrence of euhedral augite. Specific gravity=2·81 and 2·84.

A further variety of the dolerite occurs as a small outcrop on the flank of the picrite south-east of the field, adjacent to the quarry. The sections cut vary considerably, but all contain some olivine. The latter is unevenly distributed; in N 21 olivine is the chief ferromagnesian mineral, in N 22 augite is in much greater proportion. Enstatite generally accompanies the olivine when it occurs in considerable quantity. Part of the felspar is much decomposed; some undoubted andesine occurs, and is much fresher. The decomposed felspar shows no twin striation, and is considered to be orthoclase—in N 22 this forms about half the felspar. A fair amount of chlorite is present, and the iron-ore is ilmenite. Although the rock is much weathered, the olivine is notably fresh, and is not as much altered as the olivine in the picrite. Quartz forms the last product of crystallization, and contains apatite; further, the felspar is euhedral to it: hence this quartz is original.

This variety of the dolerite is very restricted in distribution, occurring only in one part in immediate contact with the picrite. All other sections of dolerite, apart from the xenoliths, contain no olivine. This particular variety is a differentiation-facies of the picrite, in which the proportion of felspar is notably increased. But this explanation is not accepted for the rest of the olivine occurrence in the xenoliths, in view of the facts just stated.

(*f*) Lower Quarry: dolerite.—The rocks here are completely chloritized, the original mineral having been augite. The felspar proves to be andesine, where it is fresh enough for a

[1] The numerals N 20, etc. refer to the slides which I have presented to the Museum of Practical Geology, Jermyn Street, London, S.W. 1.



W. G. S. photomicro.

THE COMPOSITE SILL AT NEWTON ABBOT.

determination; but much of it is chloritized, with the development of glassy-clear secondary albite. Quartz occurs in considerable quantity, both original and xenolithic; ilmenite or pyrites represents the iron-ores; and secondary minerals are epidote and calcite, the latter forming veins. The specific gravity is 2·59, this low figure being due to the altered character of the rock.

V. Summary and Conclusions.

The sill described in the foregoing pages is intrusive in the Upper Devonian formation, the intrusive character being indicated by the spotting of the slates. It has been shown that differentiation has taken place, resulting in rocks which vary from picrites through dolerites to bostonite. The picrite forms the base of the intrusion, and has slight lateral extension: it has been partly resorbed by the dolerite, with the formation of basic xenoliths in the dolerite and of xenolithic structure in the picrite; the junction is well defined. The dolerite forms the main mass, and the latest products of the differentiation are the bostonite-veins. Mugearite occurs as a modification of the dolerite. Quartz is an original constituent, and has also been obtained from outside sources, perhaps from Lower Devonian grits beneath the slates.

Differentiation has not taken place *in situ*, as the junctions do not shade one into the other, but are always sharp—except in the case of the mugearite.

The order of differentiation is of decreasing basicity, and hence probably represents a plutonic phase, although the scale of the intrusion is of the minor order.

Stratification of the picrite and dolerite took place in the magma reservoir, parts of the picrite were carried forward by the dolerite, and the bostonite was of slightly later production, but earlier than the final cooling of the sill, as it shows no selvage.

The albitic final phase of differentiation suggests a Culm age for the intrusion.

EXPLANATION OF PLATE XI.

Fig. 1. Xenolith in dolerite (N 10 A). Summit Quarry, Knowles Hill (Newton Abbot). From the central part of the xenolith. Glomeroporphyritic aggregate of chlorite and serpentine after olivine; augite-plates at the lower edge. The texture of the olivine is subhedral, as in the picrites. Ordinary light, × 30 diameters. (See p. 265.)

2. Fine-grained dolerite, 'mugearite variation' (N 14). Summit Quarry, Knowles Hill. Oligoclase-laths giving a trachytic aspect. On the right edge is a small orthoclase, north-west of this two small anhedral quartzes, while below is a small rhomb of soda-orthoclase. Crossed nicols, × 35 diameters. (See p. 267.)

3. 'Bostonite'-vein (N 9). Summit Quarry, Knowles Hill. Rhombic sections of chequer oligoclase-albite, with inclusions of chlorite. Three crystals in the central upper part on the right show coarse chequer-structure; to the left of these are two rhombs of soda-orthoclase. The central crystal shows albite-lamellæ, nearly at extinction. Crossed nicols, × 30 diameters. (See p. 266.)

4. Soda-syenite segregation in albite-diabase, West Quarry, Trusham Station. This shows sections of albite and soda-orthoclase, which

may be compared with the crystals in fig. 3. Crossed nicols, × 30 diameters. (See p. 266.)

Fig. 5. Olivine-dolerite (N 22). Edge of field, Knowles Hill. Olivine-crystal in the centre, orthoclase on the left. The remainder of the slide consists of andesine, augite, and quartz. Ordinary light, × 30 diameters. (See p. 268.)

6. Dolerite (N 18). Summit Quarry, Knowles Hill. Augite subophitic to andesine: quartz on the right. The iron-ore is ilmenite. Crossed nicols, × 30 diameters. (See p. 267.)

Discussion.

Dr. J. S. Flett welcomed this paper as a contribution to the petrography of the greenstones of Cornwall and Devon. The diabases of that province not unfrequently showed a tendency to develop an 'alkaline' facies, especially in the abundance of felspars rich in soda; but, in the speaker's experience, many of them had been extensively 'albitized,' either during crystallization or shortly after consolidation. The abundance of albite was noteworthy also in the pillow-lavas and keratophyres, which he supposed were the effusive representatives of the same magma. Analcite was very rare in these rocks, and it seemed possible that albitization occurred in place of analcitization when the post-volcanic solutions emanating from the magma were comparatively siliceous.

Mr. L. Hawkes said that two types of quartz from the dolerite were described, and it was suggested that the larger individuals with corrosion-embayments had been derived from a sandstone. The speaker asked whether these crystals were scattered evenly throughout the rock, and whether they always occurred singly. From the origin indicated by the Author one would have expected to find irregularly distributed fragments, some built of more than one individual. The speaker had found big corroded quartz-grains quite commonly in basic rocks in Iceland, where no sandstones were known, and had come to the conclusion that they had either crystallized from the basic magma, or had been incorporated from an acid one, in some way not yet satisfactorily explained.

Mr. A. K. Wells said that he had difficulty in agreeing with the use of certain rock-names for some of the specimens exhibited. In particular he would like to ask the Author whether his 'mugearite' showed any of the structural and textural peculiarities characteristic of the type-rock as defined by Dr. A. Harker from Skye. As Harker's 'mugearite' was a well-individualized type, it was perhaps undesirable to apply the term to a rock which appeared to resemble the type in one particular only—the composition of the felspar.

The Author expressed his thanks for the reception accorded to his paper. In reply to Mr. Hawkes, he stated that most of the quartz was primary, a few isolated and corroded crystals only being considered secondary. In reply to the criticism of nomenclature by Mr. Wells, he said that 'mugearite' had been used as a generalized term for oligoclase-dolerite, and 'bostonite' for an acid differentiate of a basic magma.

8. Jurassic Plants *from* Ceylon. By Prof. Albert Charles Seward, Sc.D., F.R.S., Pres.G.S., and Richard Eric Holttum, B.A. (Read January 18th, 1922.)

[Plate XII.]

The plants described in this paper were collected by Mr. E. J. Wayland, Government Geologist of Uganda, in the course of a mineral survey of Ceylon: they are the first fossil plants recorded from the island. Several small though well-defined impressions of plants were discovered at Tabbowa in the North-West Province (lat. 8° S., long. 80° E.) in a pale-yellow shale resting 'directly on Archæan rocks and folded in with them.' In writing to Dr. A. Morley Davies, from whom we received the collection, Mr. Wayland speaks of the discovery of the plant-beds as the result of 'the most arduous work' that he has ever done:—

> 'dense jungle and lateritic earth masked exposures, and mosquitoes were dreadful. The monsoon was late, and one by one men fell sick, and the day came when all the men (and headman) were down. Then, after doctoring them to the best of my ability, I proceeded to carry on the work alone, cutting my own path through the jungle and doing everything myself.'

The results obtained by Mr. Wayland are of considerable importance from a phytogeographical and a stratigraphical point of view.

PTERIDOPHYTA: **Filicales.** Fam. ? Osmundaceæ.

Cladophlebis reversa (Feistmantel) [=? Todites Williamsoni (Brongniart)]. (Pl. XII, figs. 13, 15 *a*, 15 *b*, & 16.)

The three imperfect pinnæ referred to this species are characterized by the relatively broad axis and the *Cladophlebis* type of venation. The venation is most clearly seen in fig. 15 *b*, which represents a crushed fragment with short and broadly rounded pinnules attached by the whole base. These and the more linear pinnules shown in fig. 16 agree very closely with examples of *Todites Williamsoni* figured from the Jurassic rocks of Yorkshire,[1] Graham Land[2] on the borders of Antarctica, and many other regions. The smaller specimen shown in fig. 13 may belong to the same species, but the venation is invisible. In the absence of fertile pinnules we cannot with complete confidence refer the specimens to the Osmundaceæ, although, in view of the occurrence of fertile pinnules in the Graham-Land beds and their close agreement in habit with the Ceylon fragments, an Osmundaceous affinity is probable.

[1] Seward (00) pl. xv, fig. 1. Numerals in parentheses refer to the Bibliography, p. 276.

[2] Halle (13) pl. iii, figs. 1–5.

We have no doubt of the specific identity of the Tabbowa fossils with those figured by Feistmantel[1] from the Jurassic rocks of the Madras coast as *Pecopteris reversa*, and we therefore adopt his name in preference to *Todites Williamsoni*, substituting *Cladophlebis* for *Pecopteris*.

FILICALES INCERTÆ SEDIS.

Cladophlebis denticulata Brongniart. (Pl. XII, figs. 11 *a*, 11 *b*, 12, 14 *a*, & 14 *b*.)

This designation is used in a comprehensive sense, as standing for a group of fern fronds which cannot (in the sterile condition) be assigned to well-defined species in the stricter sense.[2] The specimen shown in fig. 12, probably from near the distal end of a pinna, has falcate pinnules, while that reproduced in fig. 11 bears pinnules with more nearly parallel sides. The relatively broader pinnules seen in fig. 14 resemble in shape those of fig. 16; but the slender axis of the pinna in the smaller impression is a feature more suggestive of *Cladophlebis denticulata* than of *Todites*. In the three specimens, figs. 11, 12, & 14, the laminæ are entire and the secondary veins show a single dichotomy (figs. 11 *b* & 14 *b*). If larger specimens were available, it might be possible to differentiate between the fragmentary pinnæ; but we prefer to include them under the single group-name *Cladophlebis denticulata*, which comprises sterile fronds from Jurassic localities in almost all parts of the world.

Except in their smaller size, the Ceylon specimens agree with those figured by Oldham as *Pecopteris indica*[3] and later by Feistmantel as *Alethopteris indica* from the Rajmahal Hills,[4] also with *Alethopteris whitbiensis* figured by Feistmantel from the Jabalpur Group.[5] Two small specimens, figured by Feistmantel from the Madras coast[6] as *Alethopteris indica*, appear to be identical with the Tabbowa impressions. A small specimen figured by Halle from Graham Land[7] as *Cladophlebis* sp. is similar to that in fig. 12, and his *C. oblonga* from the same locality is indistinguishable from our examples. It is, however, impossible strictly to differentiate between pinnæ of this general type, and, unless fertile pinnules are discovered, we consider that the better course is to adopt the comprehensive group-name *Cladophlebis denticulata*.

[1] Feistmantel (79) pl. i, fig. 5; pl. ii, figs. 1, 2, & 7.
[2] For synonymy, see Seward (00) p. 134.
[3] Oldham & Morris (63) pl. xxvii.
[4] Feistmantel (77) pl. xlvi, figs. 3 & 4.
[5] Feistmantel (77^2) pl. ii, figs. 2–7.
[6] Feistmantel (79) pl. i, fig. 1.
[7] Halle (13) pl. ii, fig. 4.

FILICALES (?) or CYCADOPHYTA.

TÆNIOPTERIS SPATULATA McClelland. (Pl. XII, figs. 1–4 *b*, 5, 6 *a* & 6 *b*, 7, 8 *a* & 8 *b*, 9, 10 *a*, & 10 *b*.)

Although it has been customary to regard *Tæniopteris* as a genus of ferns, the evidence brought forward by Mr. Hamshaw Thomas,[1] in support of his contention that the European Jurassic species *Tæniopteris vittata* is a Cycadean frond, leads one to suspect that some other sterile *Tæniopteris* leaves may also be Cycadean. The species *T. spatulata* was founded by McClelland[2] on leaves which he spoke of as abundant in the Jurassic plant-beds of the Rajmahal Hills in Bengal. He described them as 'linear, 2–3 ins. long, narrow at the base, becoming broader towards the apex, or sub-spatulate.' McClelland's figure of the type-specimen, as Zeiller[3] says, does not suggest accuracy in details. There is, however, no doubt of the identity of McClelland's leaf with those subsequently figured by Oldham[4] from the same locality as *Stangerites spatulata* and by Feistmantel[5] from the Godaveri district and the Madras coast as *Angiopteridium spathulatum*.

Tæniopteris leaves are the most abundant fossils in the Tabbowa Beds. The leaves are simple, entire, linear, 2·5 to at least 5 cm. long, 0·25 to 1·5 cm. broad. Some of the fragments are probably from leaves longer than that shown in Pl. XII, fig. 1. The apex is acuminate or bluntly rounded, the lamina tapers very gradually towards the base, a strong midrib gives off lateral veins, almost at right angles, which are dichotomously branched, usually once close to the midrib or occasionally near the margin. There are 25 to 40 veins per centimetre of lamina (figs. 4 *b*, 6 *b*, 8 *b*, & 10 *b*). The lamina of the fragment seen in fig. 5 appears to be lobed, but this may be accidental. The curved form shown in fig. 9 is probably an abnormality, and may be the result of injury.

In 1860 M'Coy[6] named some leaves from Victoria *Tæniopteris Daintreei*, which (it is generally acknowledged) are identical with *T. spatulata*; but M'Coy's designation was afterwards employed by W. Carruthers for a larger and almost certainly a distinct species from Queensland. One of us, in an account of a collection of Jurassic plants from Victoria,[7] used M'Coy's specific name, in place of the older designation of McClelland, without any adequate reason, for specimens which are indubitably identical with the Ceylon leaves. Dr. Walkom[8] has more recently figured *T. spatulata*

[1] Thomas (15) p. 127.
[2] McClelland (50) pl. xvi, fig. 1.
[3] Zeiller (03) p. 76.
[4] Oldham & Morris (63) pl. vi, figs. 1–7.
[5] Feistmantel (77[3]) pl. i, figs. 6 B & 7 B; (79) pl. i, figs. 8–13 & pl. ii, figs. 3, 5–6.
[6] M'Coy (60) Proc. p. x.
[7] Seward (04) p. 168. In this paper a synonymy is given.
[8] Walkom (17) p. 30 & pl. v, fig. 2 *b*. See also Dun (98) p. 390.

from the Walloon Series of Queensland and from Jurassic rocks in New South Wales.[1] Arber has recorded *T. Daintreei*, this specific name being used instead of *T. spatulata*, from several localities in New Zealand.[2] Some leaves figured by Feistmantel from the Indwe River (Cape Province),[3] as *T. Daintreei* are indistinguishable from the Ceylon specimens. Etheridge[4] records, but unfortunately does not figure, *T. spatulata* from Natal, in association with *Glossopteris* and *Phyllotheca*. In view of the fact that in India this species is confined to beds above those containing *Glossopteris*, it would be interesting to know whether Etheridge's determination is correct. The association, in the Rhætic plant-beds of Tongking, of leaves named by Zeiller *T. spatulata*[5] and some members of the *Glossopteris* flora supports Etheridge's record; but it is noteworthy that the Tongking leaves are characterized by a well-marked transverse folding of the lamina, which imparts to them a corrugated appearance unlike any other fronds of *T. spatulata*. Although Zeiller's specimens bear a close resemblance in form and venation to those from Tabbowa, we feel some doubt as to their specific identity.

GYMNOSPERMÆ. **Coniferales.** Fam. Araucarineæ.

Araucarites cutchensis Feistmantel. (Pl. XII, fig. 17.)

The imperfect cone-scale, 1·5 cm. long, represented in fig. 17 shows the impression of a single median seed and the torn distal end of the scale, which was probably acute. Some of the smaller examples described by Feistmantel[6] from the Madras coast as *A. cutchensis* are very similar to the single cone-scale from Ceylon. This species is recorded also from Graham Land,[7] and it does not differ in any very definite characters from certain Araucarian cone-scales from European, American, and Australian localities.[8]

CONIFERALES INCERTÆ SEDIS.

Brachyphyllum mamillare Brongniart. (Pl. XII, fig. 19.)

This fragment of a slender branched shoot, although too small to be determined with certainty, appears to be identical with the finer branches of larger examples figured by Feistmantel[9] from the Jabalpur Group as *Brachyphyllum mamillare*, a widely distributed Jurassic conifer. The crowded appressed leaves, apparently

[1] Walkom (19) pl. viii, fig. 3.
[2] Arber (17) p. 46 & pl. vi.
[3] Feistmantel (89) pl. ii, fig. 11.
[4] Etheridge (01) p. 72.
[5] Zeiller (03) pl. xiii, figs. 6–12.
[6] Feistmantel (79) pl. xiv, figs. 6–9 & pl. xvi, fig. 15.
[7] Halle (13) pl. viii, figs. 3–10.
[8] Seward (19) p. 264.
[9] Feistmantel (77[2]) pl. xiii, fig. 1.

disposed spirally, and the habit of the twig support a reference to *Brachyphyllum*. Some American Cretaceous examples of *Brachyphyllum* have been assigned on anatomical grounds by Jeffrey to the Araucarineæ, but it would be rash to assume this affinity for all the numerous impressions included in the genus.

Elatocladus plana (Feistmantel). (Pl. XII, fig. 20.)

The piece of foliage shoot shown in fig. 20 bears two-ranked leaves spirally disposed, reaching a length of 3 cm. and barely 1 mm. broad. There is a well-marked midrib, and the lamina tapers gradually towards an acute apex; the lower margin is decurrent. Shoots of this type are figured by Feistmantel [1] from the Madras coast as *Taxites planus*. In view of the impossibility of determining the affinity of specimens such as these, we adopt the non-committal generic name *Elatocladus*.

PLANTA INCERTÆ SEDIS.

Desmiophyllum sp. (Pl. XII, figs. 18 *a* & 18 *b*.)

This fragment of a linear leaf, 3·5 mm. broad, has seven parallel veins about 0·5 mm. apart. The impression is not sufficiently well preserved to demonstrate the presence or absence of interstitial 'veins.' It may be a piece of a *Podozamites* leaf, a leaf of *Phœnicopsis*, or a fragment of a Cycadean leaflet. It agrees closely with some of the specimens from Indian Jurassic beds named by Feistmantel [2] *Podozamites lanceolatus*, and it is also very similar to a small specimen figured by Feistmantel from the Madras coast [3] as a piece of a Cycadean leaflet. In view of the impossibility of determining accurately the specimen, we employ the convenient designation *Desmiophyllum*.[4] It is, however, noteworthy that while *Podozamites* is known from Indian beds, *Phœnicopsis* has not been recorded from the Gondwana Series.

Conclusion.

The following is a list of our determinations :—

Cladophlebis reversa (Feistmantel)
[= *Todites Williamsoni* (Brongniart)].
Cladophlebis denticulata Brongniart.
Tæniopteris spatulata McClelland.
Araucarites cutchensis Feistmantel.
Brachyphyllum mamillare Brongniart.
Elatocladus plana (Feistmantel).
Desmiophyllum sp.

Five of these species we believe to be identical with plants recorded by Feistmantel from the Madras coast, and in all

[1] Feistmantel (79) pl. xiii; pl. xiv, figs. 1, 2, 4 & 5.
[2] *Id.* (77^2) pl. iii, figs. 7–14 & pl. iv; (79) pl. ix, figs. 9 & 10.
[3] *Id.* (79) pl. ix, fig. 11.
[4] For the application of this name, see Seward (19) p. 70.

probability *Desmiophyllum* sp. is identical with some of the imperfect leaves from the Indian beds. It is significant that the rocks in the Madras region containing Jurassic plants are said by Medlicott & Blanford [1] to rest unconformably on gneissose strata, presumably of Archæan age. From Trichinopoli, where these Madras beds are represented, the distance to Tabbowa in Ceylon is about 200 miles, and in both localities there appears to be the same relation to older igneous rocks. In our opinion, the flora is unquestionably Jurassic in age, and probably dates from the Lower Oolite. Formerly, the Madras beds were included as the Kota Series with the Maleri Series; but recently Mr. G. de P. Cotter [2] has shown good reason for separating the Kota from the Maleri Series, and assigning it to a Lower Oolite and Upper Liassic horizon. The palæobotanical evidence is consistent with this conclusion.

Bibliography.

Arber, E. A. N. (17) 'The Earlier Mesozoic Floras of New Zealand' N.Z. Geol. Surv., Pal. Bull. 6, 1917.

Cotter, G. de P. (17) 'A Revised Classification of the Gondwana System' Rec. Geol. Surv. India, vol. xlviii (1917) pt. 1, pp. 23–33.

Dun, W. S. (98) 'Notes on the Australian Tæniopterideæ' Trans. Austr. Assoc. Advancem. Sci. 1898, p. 384.

Etheridge, R., Jun. (01) 'Notes on Fossil Plants from the St. Lucia Bay Coalfield, Enseleni River (Zululand)' First Rep. Geol. Surv. Natal & Zululand (1901) p. 69.

Feistmantel, O. (77) 'Jurassic (Liassic) Flora of the Rajmahal Group in the Rajmahal Hills' Mem. Geol. Surv. India, Palæont. Indica, ser. ii, pt. 2, 1877.

Do. (77²) 'Flora of the Jabalpur Group (Upper Gondwanas) in the Son-Narbada region' Palæont. Indica, ser. xi, pt. 2, 1877.

Do. (77³) 'Jurassic (Liassic) Flora of the Rajmahal Group from Golapili, near Ellore, South Godavari' Palæont. Indica, ser. ii, pt. 3, 1877.

Do. (79) 'Upper Gondwana Flora of the Outliers of the Madras Coast' Palæont. Indica, ser. ii, pt. 4, 1879.

Do. (89) 'Uebersichtliche Darstellung der Geologisch-Paläontologischen Verhältnisse Süd-Afrikas' pt. i, Abhandl. Königl. Böhmisch. Gesellsch. Wissensch. ser. 7, vol. iii (1889).

Do. (90) 'Geological & Palæontological Relations of the Coal & Plant-bearing Beds of Palæozoic & Mesozoic Age in Eastern Australia & Tasmania, &c.' Mem. Geol. Surv. N.S.W., Palæontology, No. 3, 1890.

Halle, T. G. (13) 'The Mesozoic Flora of Graham Land' Wiss. Ergeb. Schwed. Südpolar-Exped. 1901–1903, vol. iii, pt. 14, 1913.

McClelland, J. (50) 'Report of the Geological Survey of India for the Season of 1848–49' Calcutta, 1850.

M'Coy, F. (60) Trans. R. Soc. Victoria, vol. v (1860) Proc. p. x.

Medlicott, H. B., & W. T. Blanford. (93) 'A Manual of the Geology of India' Calcutta, 1893.

Oldham, T., & J. Morris. (63) 'Fossil Flora of the Rajmahal Series in the Rajmahal Hills' Palæont. Indica, ser. ii. pt. 1, 1863.

Seward, A. C. (00) 'Catalogue of the Mesozoic Plants in the Department of Geology, British Museum—Part III, The Jurassic Flora: I—The Yorkshire Coast' London, 1900.

Do. (04) 'On a Collection of Jurassic Plants from Victoria' Rec. Geol. Surv. Victoria, vol. i (1904) pt. 3, p. 155.

Do. (19) 'Fossil Plants' vol. iv. Cambridge, 1919.

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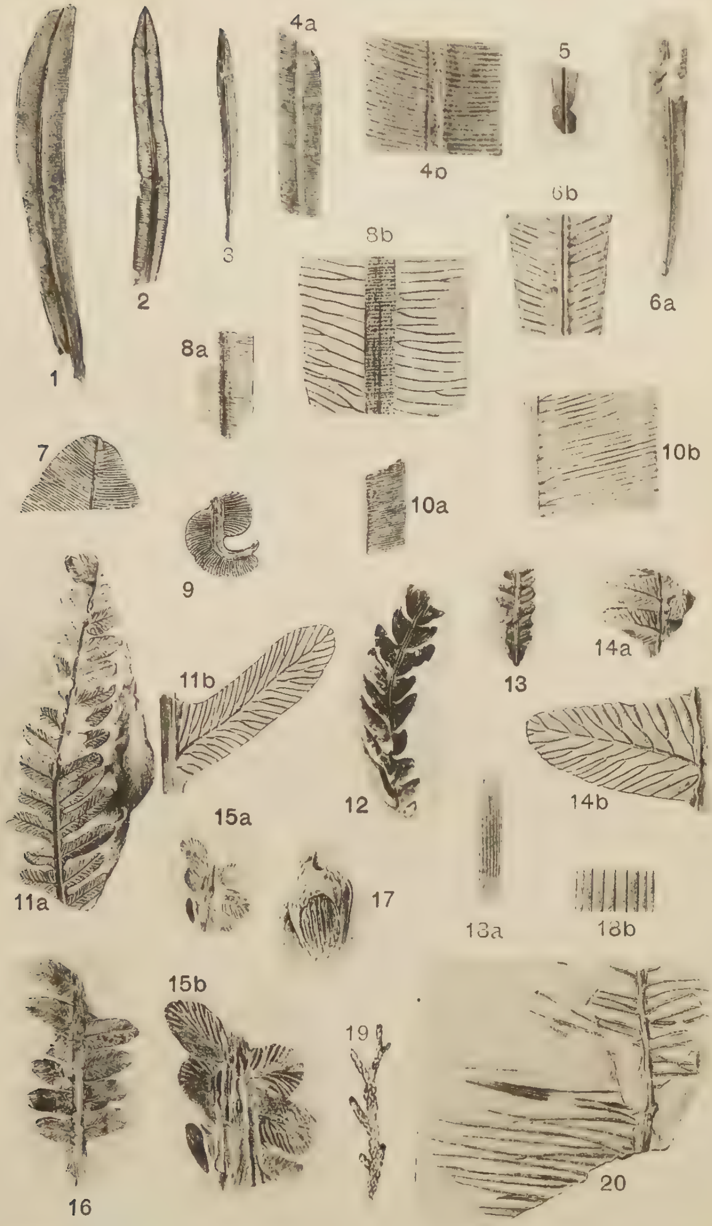
[1] Medlicott & Blanford (93) p. 182.

[2] Cotter (17) p. 25.



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TÆNIOPTERIS (FIGS. 1-10); CLADOPHLEBIS (FIGS. 11-16);
ARAUCARITES (FIG. 17); DESMIOPHYLLUM (FIG. 18);
BRACHYPHYLLUM (FIG. 19); ELATOCLADUS (FIG. 20);

THOMAS, H. HAMSHAW. (15) 'On *Williamsoniella*, a New Type of Benettitalean Flower' Phil. Trans. Roy. Soc. ser. B, vol. ccvii (1915) p. 113.
WALKOM, A. B. (17) 'Mesozoic Floras of Queensland, Part I: The Flora of the Ipswich & Walloon Series: (*c*) Filicales' Geol. Surv. Queensl. Publication No. 257 (1917).
Do. (19) 'On a Collection of Jurassic Plants from Bexhill, near Lismore (N.S.W.)' Proc. Linn. Soc. N.S.W. vol. xliv, pt. 1 (1919) p. 180.
ZEILLER, R. (03) 'Flore Fossile des Gîtes de Charbon du Tonkin' Etudes des Gîtes Minéraux de la France: Colonies françaises, Paris, 1903.

EXPLANATION OF PLATE XII.

[All the figures are drawn of the natural size, except those with numbers followed by *b*.]

Figs. 1–10 *b*. *Tæniopteris spatulata*. 4 *b*, 6 *b*, 8 *b*, 10 *b* × 3.
11 *a*, 11 *b*, 12, 14 *a*, 14 *b*. *Cladophlebis denticulata*. 14 *b* × 3.
13, 15 *a*, 15 *b*, 16. *Cladophlebis reversa*. 15 *b* × 2.
Fig. 17. *Araucarites cutchensis*.
Figs. 18 *a* & 18 *b*. *Desmiophyllum* sp. 18 *b* enlarged.
Fig. 19. *Brachyphyllum mamillare*.
20. *Elatocladus plana*.

DISCUSSION.

Dr. A. MORLEY DAVIES said that the discovery of these Jurassic plants was the outcome of the enthusiasm of Mr. Wayland, who had made the collection in circumstances of the greatest difficulty. He greatly regretted that Mr. Wayland, who was on his way to England, had not been able to be present to give an account of his field-work.

The PRESIDENT (Mr. R. D. OLDHAM) commented on the interest attaching to the discovery of these beds in Ceylon, as carrying on the deposits known in the Madras coastal region, and extending the length of the margin of the continent of Gondwanaland which had been previously traced.

9. *On a* COLLECTION *of* CARBONIFEROUS PLANTS *from* PERU.[1] By Prof. ALBERT CHARLES SEWARD, Sc.D., F.R.S., Pres.G.S. (Read April 12th, 1922.)

[PLATE XIII.]

IN the course of a geological expedition to Peru in 1911 Mr. J. A. Douglas collected some fossil plants from coal-bearing strata on the south side of the peninsula of Paracas, a few miles south of the port of Pisco (lat. 13° 45′ S.). The plants, which are the property of the Geological Department of Oxford University, were handed to me for identification by Mr. Douglas, who also supplied information on the geology of the district. The specimens, though fragmentary and few in number, are worth recording, since this is the only known occurrence of fossiliferous Palæozoic rocks on the coast of Peru.[2] Moreover, from a phytogeographical point of view, any fossil plants from South America are worthy of attention.

The coal occurs in a series of greenish sandstones and grey and black carbonaceous shales, which have a north-easterly strike and dip about 25° south-eastwards. These are overlain unconformably on the neck of the peninsula by Tertiary sandstones and impure limestones. There is no definite stratigraphical evidence of the age of the coal-bearing beds, and the plants are therefore of special importance: in other districts the strata which are the chief source of Peruvian coal are Mesozoic in age. Mr. Douglas informed me that the rocks in question were described by Friedrich Fuchs,[3] who published a note on them in 1900 in the 'Boletin de Minas' (Lima). Fuchs recorded the following species, and assigned the beds to the Upper Coal Measures:—

Calamites Suckowi Brongniart. C.	*Lepidodendron Sternbergii* Brongniart. C.
Sphenopteris Hartlebeni Dunker. W.	*Sigillaria tessellata* Brongniart. C.
Baiera pluripartita Schimper. W.	*Stigmaria ficoides* Brongniart. C.

Four of these species (C) are well-known Northern Hemisphere Carboniferous plants and two (W) are Wealden species. It is obviously impossible to express an opinion on the nature of Fuchs's specimens. A short account of the geology of the district is given by Mr. V. F. Marsters, who states that Fuchs mapped the whole area as Carboniferous, the plants being typical Carboniferous species: the fact that two species are characteristic of European

[1] After this note had been sent to the Geological Society, a preliminary paper on 'Carboniferous Plants from Peru' by E. W. Berry, to be followed by a fully illustrated account, was published in the 'American Journal of Science' ser. 5, vol. iii (1922) p. 189. Mr. Berry's conclusion is that the Paracas plant-beds 'correspond to the Westphalian stage.'—[A. C. S.]

[2] Douglas (21) p. 250. Numerals in parentheses refer to the Bibliography, p. 283.

[3] This paper has not been seen, either by Mr. Douglas or by myself.

Wealden floras was not noticed. The account of the geology of the district by Marsters is as follows:—

'The geology of this district was studied by Don Federigo Fuchs, and according to his map the whole area is Carboniferous. The area termed Cerro de la Mina is occupied by Carboniferous strata, as the fossil flora indicates; the plants are typical species of the Carboniferous Period. The best exposure of the beds is to be seen on the coast between the house of the Director of the Exploration Company and the Punta de Huaca. This shows thick beds of sandstone with thin and fissile shales, the coal being associated with the shales; local folding, attenuation, and pinching-out of the seams are common phenomena. The dip of the strata varies in direction from S. 40° E. to S. 45° E., at angles between 16° and 27°. If we examine also the north-western boundary of the Cerro de la Mina on the south-eastern slope of the little valley of the Arquillo, we observe the same lithological conditions as in the former region. The Carboniferous strata are clearly in contact with rocks which are, without any doubt, Tertiary. In many places the shales are very carbonaceous, containing at times thin lenticles of pure coal. The dip of the beds varies from 16° to 20°; the whole formation is inclined towards the south-east.

'After having visited this region, Señor Bravo states that west of the Cerro de la Mina Carboniferous sediments exist in the neighbourhood of the Punta de Lechuza.' [1]

To Mr. Douglas I am also indebted for the following extract from a paper by Prof. C. I. Lisson (13):—

'In the year 1900 Prof. Fuchs published the discovery of a Carboniferous flora situated on the peninsula of Paracas. Although a revision of the determinations adopted by Fuchs is necessary, nevertheless it is a proved fact that the plants show decisively the presence of a Carboniferous deposit.'

Here again is no reference to the fact that Fuchs's list included some typical Wealden plants.

In view of the inclusion of two Wealden species in the list of plants given by Fuchs, it is noteworthy that the occurrence of a Wealden flora was recorded in Peru in 1907 and 1910.[2]

A photograph of the coal-bearing beds on the Pacific coast is published in a book by R. Enock[3] on the Andes and the Amazon: this author speaks of the coal-deposits of Peru as one of the country's most valuable assets. These carbonaceous deposits are of Mesozoic, and not of Palæozoic age.

So far as I am aware, no Upper Carboniferous flora, in which are not included members of the *Glossopteris* flora, has been described from South America.

Description of the Specimens.

SPHENOPTERIS sp. (Pl. XIII, figs. 1–3.)

The collection includes several fragments of pinnæ, pieces of rachis, and pinnules of a fern-like plant, although these are unfortunately not sufficiently well preserved to be identified with

[1] Marsters (09) pp. 40–41. This extract is taken from a translation kindly made for me by Mr. Douglas.

[2] Neumann (07); Zeiller (10).

[3] Enock (07) p. 207.

certainty. The best specimen is shown in Pl. XIII, fig. 1: the branched axis is longitudinally striated and smooth; the pinnules are more or less deltoid, deeply dissected, and the ultimate segments are obtuse or truncate. A smaller piece of pinnule is reproduced in Pl. XIII, fig. 2. The broader piece of rachis seen in Pl. XIII, fig. 3, if found without any associated pinnules, might be mistaken for a portion of a *Cordaites* leaf.

Fig. 1 recalls *Sphenopteris furcata* Brongniart, an Upper Carboniferous species by some authors referred to *Diplotmema* or *Palmatopteris*; but in the Peruvian pinnules the segments are obtuse, and not acute as in *Sphenopteris furcata*. Comparison may also be made with *Eremopteris missouriensis* Lesquereux, as figured by D. White[1] from the Lower Coal Measures of Missouri, in which the ultimate segments are obtuse or truncate. Specific determination is probably impossible, and the occurrence of ferns or pteridosperms, in both Upper and Lower Carboniferous strata, with pinnules very similar to those shown in figs. 1 & 2, precludes any definite conclusion as to the question of geological age. Several Lower Carboniferous species have been figured, in which the pinnules bear a very close resemblance to the Peruvian specimens; the deeply-dissected form of the lamina suggests comparison with pinnules of species of *Rhodea* and *Sphenopteridium*.[2]

Lepidodendron sp. (Pl. XIII, figs. 4–6.)

This specimen, part of which is shown in fig. 4, is an impression on a carbonaceous sandstone of a piece of a stem or branch 16·5 cm. long and 3 cm. wide, with several attached and indistinctly preserved leaves spreading over the rock at the edges. The fossil is doubtless part of a Lepidodendroid plant; the surface does not reveal at all clearly the form of the leaf-cushions, except at the lower end. An examination of the carbonized surface shows impressions of linear leaves pressed against the stem. Fig. 5 represents a single leaf-cushion, with a leaf-scar and the impression of part of a leaf. The specimen seen in fig. 6 shows more clearly the form of the leaves, each of which has a midrib.

These specimens unfortunately do not enable one to determine with any confidence the precise age of the plant-beds, as Lepidodendroid plants generally resembling that from Peru occur in both Upper and Lower Carboniferous strata.

Sigillaria sp., or Lepidodendron sp. (Pl. XIII, figs. 7 & 8.)

The two specimens reproduced in figs. 7 & 8 are pieces of a stem having contiguous leaf-cushions which bear leaf-scars agreeing both with some types of Sigillaria, as, for example, *Sigillaria Brardi* Brongniart, and with certain species of *Lepidodendron*. On the upper part of several leaf-cushions there is a small circular scar,

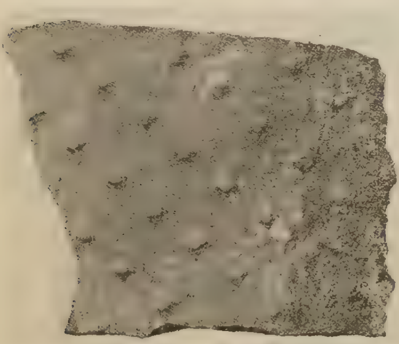
[1] White (99) pl. v, figs. 1–3 *a* & pp. 6–19.
[2] See Nathorst (20) pl. i, figs. 11–13.

presumably a ligule-pit. No vascular-bundle scars or parichnos-scars can be detected. *Sigillaria Brardi*, although mainly a Northern Hemisphere Upper Carboniferous species, is recorded also from South Africa [1] and Brazil.[2] Some of the numerous specimens figured by E. Weiss as *Sigillaria mutans* Weiss [3] closely resemble the small pieces shown in figs. 7 & 8. On the other hand, comparison may equally well be made with species of *Lepidodendron* from Lower as well as from Upper Carboniferous beds.

Bothrodendron (?) sp. (Pl. XIII, fig. 9, and text-figure.)

Although it is by no means certain that the specimens shown in Pl. XIII, fig. 9 and in the text-figure belong to the same species, they may be considered together and regarded as possibly specifically identical, or at least very closely allied. The flattened piece of stem seen in fig. 9 is characterized by the spirally-disposed and widely-separated, slightly-prominent leaf-scars. Most of the surface is bereft of any carbonaceous film, and does not exhibit the original surface-features; but, on the right-hand side, a thin carbonaceous layer probably represents the actual surface, and on magnification the outlines of cells are clearly visible. The leaf-scars are prominent, transversely elongated, and rhomboidal. On the partly-decorticated surface there are discontinuous longitudinal ridges and an irregular transverse wrinkling, but on the carbonized film no wrinkling is seen. There is no indication of any leaf-cushion, no ligular pit, and only a very faint suggestion in a few of the scars of a median vascular scar. The leaf-scars shown in the text-figure are rather more rounded, and appear as slightly concave areas (not projecting as in Pl. XIII, fig. 9).

Bothrodendron (?) *sp. (Natural size.)*



In the small and widely-separated leaf-scars these fragments agree with *Bothrodendron*, *Pinakodendron*, and *Asolanus*. The form of the leaf-scar and the absence of a leaf-cushion are features more suggestive of *Bothrodendron*. The last-named genus extends from the Upper Devonian to the Upper Carboniferous.

[1] Seward (97) p. 326.
[2] White (08) p. 458.
[3] Weiss (93) pp. 84 *et seqq.*

Planta incertæ sedis. (Pl. XIII, fig. 10.)

On one piece of sandstone there are faint impressions of crowded branched filaments, some of which are shown in fig. 10. Their occurrence in a fairly-dense mass reminds us of the branched leaves of *Dicranophyllum Richiri* Renier [1] from the Coal Measures of Belgium; but they are more probably portions of pinnules of a fern-like plant, such as some of the Lower Carboniferous species referred to *Rhodea* or *Sphenopteridium*. Generic determination is hardly possible.

Conclusion.

Mr. Douglas, in his recent paper on 'Geological Sections through the Andes of Peru & Bolivia,' referred to the importance of obtaining accurate determinations of the plants which he collected from the Peruvian strata.[2] After a careful examination of the material, I submitted most of the specimens to Dr. Kidston,[3] who kindly expressed his opinion thereon. My first impression led me to regard the Peruvian plants as Upper Carboniferous in age, and this conclusion, if correct, would raise a question of considerable interest, in view of the fact that no member of the *Glossopteris* flora is included in Mr. Douglas's collection. Dr. Kidston, however, is inclined to regard the palæobotanical evidence as more favourable to a Lower Carboniferous horizon. A re-examination of the specimens in the light of his suggestions caused me to modify my conclusions. The plants are too imperfect to serve as trustworthy guides: the rocks may belong to the upper part of the Carboniferous formation or, on the whole more probably, to the Lower Carboniferous. Lower Carboniferous plants similar to Northern Hemisphere types have previously been recorded from South America; but, so far as I am aware, no Upper Carboniferous flora is known from South America composed exclusively of Northern Hemisphere types, with no admixture of members of the *Glossopteris* flora. The inclusion of two Wealden species in the list given by Fuchs must be attributed to incorrect determinations; none of the specimens collected by Mr. Douglas can reasonably be referred to a Mesozoic flora. Further research is greatly to be desired, since the available data are inadequate as a basis for any positive statement.

My thanks are due to Mr. R. E. Holttum, of St. John's College, Cambridge, for assistance given to me in the preparation of this paper.

[1] Renier (10) pl. cxvii.

[2] Douglas (21) p. 250.

[3] I am greatly indebted to my friend, Dr. Robert Kidston, F.R.S., for his helpful criticisms and suggestions.

T. A. BROCK DEL.

SPHENOPTERIS; LEPIDODENDRON;
BOTHRODENDRON (?), ETC.

Bibliography.

DOUGLAS, J. A. (21) 'Geological Sections through the Andes of Peru & Bolivia: III—From the Port of Callao to the River Perene' Q. J. G. S. vol. lxxvii (1921) p. 246.

ENOCK, R. (07) 'The Andes & the Amazon' London, 1907.

FUCHS, F. (00) 'Nota sobre el Terreno Carbonifero de Paracas' Boletin de Minas, Lima, 1900.

LISSON, C. I. (13) 'Edad de los Fosiles Peruanos & Distribucion de sus Depositos en la Republica' Lima, 1913, p. 15.

MARSTERS, V. F. (09) 'Informe sobre la Costa Sur del Peru' Bol. del Cuerpo de Ingenieros de Minas del Peru, No. 70, 1909.

NEUMANN, R. (07) 'Beiträge zur Kenntniss der Kreideformation in Mittel-Peru' Neues Jahrb. Beilage-Band xxiv (1907) p. 69.

NATHORST, A. G. (20) 'Zur Kulmflora Spitzbergens' Stockholm, 1920.

RENIER, A. (10) 'Documents pour l'Etude de la Paléontologie du Terrain houiller' Liége, 1910.

SEWARD, A. C. (97) 'On the Association of *Sigillaria* & *Glossopteris* in South Africa' Q. J. G. S. vol. liii (1897) p. 315.

WEISS, E. (93) 'Die Sigillarien der Preussischen Steinkohlen- & Rothliegenden-Gebiete: II' Abhandl. k. Preuss. Geol. Landesanst. pt. 2 (1893).

WHITE, D. (99) 'Fossil Flora of the Lower Coal Measures of Missouri' U. S. Geol. Surv. Monogr. xxxvii (1899).

WHITE, D. (08) 'Final Report of Dr. I. C. White, Chief of the Brazilian Coal Commission: Pt. III—Fossil Flora of the Coal Measures of Brazil (by D. White)' Rio de Janeiro, 1908.

ZEILLER, R. (95) 'Note sur la Flore Fossile des Gisements Houillers de Rio Grande do Sul' Bull. Soc. Géol. France, ser. 3, vol. xxiii (1895) p. 601.

ZEILLER, R. (10) 'Sur quelques Plantes Wealdiennes du Pérou' C. R. Acad. Sci. Paris, vol. cl (1910) p. 1488.

EXPLANATION OF PLATE XIII.

[The drawings, with the exception of that reproduced in fig. 5, were made by Mr. T. A. Brock.]

Fig. 1. *Sphenopteris* sp. Branched axis and pinnule. Natural size.
2. *Sphenopteris* sp. Smaller pinnule. Natural size.
3. *Sphenopteris* sp. Piece of rachis, enlarged.
4. *Lepidodendron* sp. Natural size.
5. *Lepidodendron* sp. Leaf-cushion; slightly enlarged. l = impression of a leaf above the leaf-scar.
6. *Lepidodendron* sp. Natural size.
7. *Sigillaria* sp. or *Lepidodendron* sp. Natural size.
8. *Sigillaria* sp. or *Lepidodendron* sp. Natural size.
9. *Bothrodendron* sp. Leaf-scars as depressions. Natural size.
10. *Planta incertæ sedis.* Natural size.

Discussion.

Mr. J. A. DOUGLAS, after expressing his gratitude to the Author for the trouble which he had taken in studying this collection, pointed out the possibility that the Wealden species recorded by Fuchs among Carboniferous forms were derived from the Cretaceous plant-bearing beds of the Island of San Lorenzo, and had become mixed with a collection from Paracas.

The speaker considered that the correct identification of these plants was of great importance, apart from clearing up the anomaly in Fuchs's list. David Forbes's statement that nowhere have we evidence of the existence of Carboniferous beds on the

whole coast of South America was now definitely shown to be incorrect.

This isolated Palæozoic fragment of Paracas must clearly be assigned to the coastal Cordillera, as distinct from the Mesozoic Western Cordillera, and its existence led to the hope that other fossiliferous Palæozoic rocks still awaited discovery among the crystalline rocks of the coast of Southern Peru. Further, the evidence afforded by these fossil plants seemed to support the view that the Andean Cordilleras, although subjected to repeated oscillation, had their origin at a very much earlier date than was generally recognized.

On stratigraphical grounds, it could be shown that an uplift took place during the interval between Mid-Devonian and Permo-Carboniferous times; and the surmise that the altitude of the chain thus formed fell little short of that attained by the existing range was suggested by the dissimilarity between the flora of the Pacific region and that of Gondwanaland on the east. At the present day the snowclad chain forms an effective barrier to plant-migration. Was it too much to suggest that similar conditions prevailed in late Palæozoic times? At any rate, it seemed to the speaker that the argument in favour of a land-barrier separating the two regions was more plausible than one in favour of a barrier formed by the sea.

10. Description *of a* New Plesiosaur *from the* Weald Clay *of* Berwick (Sussex). By Charles William Andrews, B.A., D.Sc., F.R.S., F.G.S. (Read February 22nd, 1922.)

[Plates XIV & XV.]

The Plesiosaurian remains which form the subject of the present paper were contained in a large septarian nodule from the Upper Weald Clay of Berwick (Sussex). This nodule was found in the excavations made by the Cuckmere Brick Company; it was broken into many fragments which were, so far as possible, collected by Mr. S. Tooth, M.Inst.C.E., and by him presented to the British Museum (Natural History). The pieces, many of which clearly contained portions of bones, were reunited, and the gaps resulting from the loss of fragments filled in with plaster of Paris, so that the original form of the nodule was restored. The extremely hard matrix was then slowly and with great skill chiselled away by Mr. L. Parsons, who found that it enclosed a mass of bones for the greater part thrown together in the utmost confusion, with the result that their removal was a matter of extreme difficulty. Despite these drawbacks, however, he succeeded in getting out the hinder part of the skull and a nearly complete shoulder-girdle, all the elements of which seem to be quite undistorted by pressure, a most unusual circumstance. The humeri were also found, but the rest of the paddles, which probably projected beyond the limits of the concretion, was lost. Numerous cervical and dorsal vertebræ, ribs, and ventral ribs were found; but of the pelvis and hinder limb nothing remained, and only one or two imperfect caudal vertebræ were preserved.

The skull (Pl. XIV, figs. 1 & 2).—This is unfortunately very imperfectly preserved, the region in front of the orbits being entirely lost. The posterior portion is also imperfect; but one exoccipital bone and the supra-occipital were found lying apart. The palate is well preserved on the right side, as far forwards as the anterior end of the sub-orbital vacuity.

The occipital condyle (*oc.c.*) forms nearly a hemisphere, its upper border only being somewhat flattened. Ventrally and laterally it is bounded by a slight groove, but one cannot say that it is pedunculate. In front of this groove the face of the bone curves sharply downwards below and outwards at the sides. Ventrally it terminates in the sharp posterior border of the flat platform presumably formed mainly by the basisphenoid, but actually covered by the parasphenoid, which conceals the relations between the basioccipital and the basisphenoid. Laterally the basioccipital passes out into a pair of tuberosities (tubera sphenoccipitalia) which terminate in flat facets looking outwards and a little downwards. The portion of the parasphenoid (*pas*) covering the basioccipital

and basisphenoid has a peculiarly roughened surface; externally it must have joined the pterygoids, but the line of junction between the two elements cannot be seen. Between the posterior interpterygoid vacuities (*p.i.v.*) the parasphenoid becomes Y-shaped, the Y being considerably above the general level of the palate; while the other arm of the Y forms a high sharp crest separating the two vacuities, in front of which the bone widens out into a flat plate wedged in between the converging anterior ends of the pterygoids. These (*pt*) are very large bones, of the usual triradiate form. The posterior wing is long, and extends back to the quadrate, which is situated far back behind the level of the occipital condyle: this portion of the bone is a nearly vertical plate, with a thickened ventral border. Anteriorly it joins the basis cranii, but its relations to the parasphenoid and basisphenoid are obscure: it is possible that the pterygoid may have overlapped the basis cranii to a considerable extent. In front of this junction the bone is wide, and its inner and outer borders are nearly parallel for some distance: there is some evidence that in this region there was a median longitudinal ridge on the palatal surface. About opposite the middle of the interpterygoid vacuities the outer border turns sharply outwards to form the posterior border of the lateral wing, and at the same time the anterior limit of the temporal vacuity. Towards its outer angle this border is raised into a ridge and thickened for union with the transpalatine bone, which unfortunately is not preserved on either side. As already mentioned, the pterygoid unites with the parasphenoid in front of the posterior interpterygoid vacuities (*p.i.v.*) and, in front of this again, meets its fellow in the middle line, there being no anterior interpterygoid vacuity such as occurs in some Plesiosaurs (for instance, *P. capensis*). Externally the anterior wing unites with the palatine, and doubtless anteriorly joined the vomers; but this portion is broken away.

The palatine (*pal.*) unites with the outer border of the anterior wing of the pterygoid, extending back to the anterior border of the lateral wing. It forms the inner and anterior border of the suborbital vacuity, uniting with the maxilla in front. The upper surfaces of the pterygoids about opposite the level of the middle of the interpterygoid vacuities unite with the bases of a pair of bones, the epipterygoids, which run up towards the lower edge of the parietals; but their union with those bones has been broken, in consequence of the compression that the skull has undergone.

The quadrates (*q.*) unite with the pterygoids by their inner border, and are extensively overlapped by the squamosals on their posterior and outer sides. Their anterior face is concave from side to side. The articular surface for the mandible is wide from side to side and narrow from before backwards, thickening a little towards its outer end.

The squamosals (*sq.*) are of the usual triradiate form; their lower limb overlaps, and unites closely with, the quadrates: the anterior (zygomatic) process runs forwards, doubtless uniting with

the jugal and postorbital, completing the outer boundary of the relatively large temporal fossa. The upper limb of the squamosal runs upwards to the parietals, forming with them the posterior border of the temporal fossa; it cannot be determined whether the squamosals meet in the middle line above the parietals.

The parietals (*par.*) form a Λ-shaped roof to the cranial cavity; posteriorly (as just described) they are overlapped by the squamosals: towards the middle of the temporal fossa they narrow, and rise in the middle line into a high sagittal crest which is interrupted by a rather large pineal foramen, situated about opposite the hinder border of the orbits. In front of this the ridge is continued forwards on to the frontal, and, at the level of the front of the orbits (*orb.*), it is very prominent, and is separated from those openings by a well-marked channel. On the left side in this specimen there is an element uniting with the outer edge of the frontals, and forming a rounded upper border to the hinder part of the orbit: this is doubtless the post-frontal. Between this element and the temporal arcade is seen the impression of another bone, the postorbital; this probably united with the jugal below, but the limits of these elements are obscure.

On the right side the anterior border of the orbit seems to be formed by a bar of bone (*p.f.*) curving up from the maxilla towards the frontals (? prefrontals); it cannot be determined whether this bone is entirely composed of maxilla, or whether it may include other elements, such as the prefrontals.

The maxilla forms most of the lower border of the orbit; on the palatal surface it widens out, and seems to have borne teeth about as far back as the middle of the suborbital vacuity. In front its suture with the palatine can be seen, but posteriorly its relations with the jugal and other elements are obscure.

The unfortunate loss of the anterior portion of the skull makes it impossible to say to what extent the snout was elongated, and renders comparison with other forms difficult. In a general way, it may be stated that the temporal fossa is larger in proportion to the orbit than in most Plesiosaurs. The region of the parasphenoid and the posterior interpterygoid vacuities seem to be the most useful for purposes of comparison, the thin sharp edge of the parasphenoid separating the vacuities being very characteristic. In most Plesiosaurs this region of the parasphenoid is wide: for example, in *Plesiosaurus macrocephalus*[1] it is broad, and has a flattened ventral surface: this seems to be the case also in *Cryptocleidus*, *Murænosaurus*, *Tricleidus*, *Dolichorhynchops*, and to a less degree in *Brachauchenius*. The skull of *Microcleidus homalospondylus* (Owen) from the Upper Lias of Whitby approaches the specimen here described in the form of its parasphenoid; but differences in the skull and other parts of the skeleton exclude the possibility of any near relationship. Unfortunately, the skull of *P. arcuatus* is not known. In the nearly contemporary *Branca-*

[1] Q. J. G. S. vol. lii (1896) p. 246.

saurus brancai Wegner, from the Wealden of Germany,[1] the parasphenoid seems to have been very similar to that of our specimen; but, on the other hand, the orbits are much larger in proportion to the temporal fossa and much longer than high. *Plesiosaurus capensis* Andrews[2] is also very similar to the specimen now described in the form of its parasphenoid; but here also differences are noticeable. Thus in *P. capensis* the orbits are larger, the pterygoids narrower where they form the outer side of the posterior interpterygoid vacuities, and there is an anterior interpterygoid vacuity; this last character may, however, be a consequence of the crushing to which the skull has been subjected. On the whole, the skull seems to resemble that of *P. capensis* most nearly, and probably like it had a short snout somewhat widened in the premaxillary region. It will be shown below (p. 291) that the likeness to *P. capensis* extends to the cervical vertebræ.

The vertebral column is represented by (1) ten cervical centra from the anterior part of the neck, eight being developed out of the matrix; (2) nine or ten posterior cervicals (the anterior five being represented by the arches only); three or four transitional (thoracic) vertebræ (both arches and centra preserved), then six dorsals, the posterior three represented by the arches only: all these form a united series; (3) about six dorsal centra free from the matrix; and (4) two or three caudal centra. Some neural arches still remain in the block of matrix.

The anterior cervical centra (Pl. XIV, figs. 3 & 4) are very imperfect, and much deformed by cracks filled with calcite. The smallest one must have come from immediately behind the axis: it is too imperfect to supply complete measurements, but its length in the mid-ventral line is about 19 mm., and its width is considerably greater than its height. From this and two or three rather larger specimens of cervical centra it can be seen that the articular face was formed by a broad, somewhat convex, outer rim within which is a well-defined deep central concavity. At the bottom of this concavity in some cases, a pit marking the position of the notochord can be seen. The third of the cervical centra (Pl. XIV, fig. 3) in point of size measures 2·2 cm. in length, 2·5 cm. in width, and 2·5 cm. in height. Another from rather farther back in the neck is better preserved, and shows very well the deep concavity of the central portion of the articular surface surrounded by a broad convex border. The central depression on the anterior face seems to be more strongly defined than that of the posterior face. The dimensions of this centrum are:—length = 25 mm.; width = 38 mm.; height = 30 mm.; one of the cervical ribs is present, its base occupying nearly the whole length of the centrum. The last of the free centra (Pl. XIV, fig. 4) also has one rib (*r.*) attached; its dimensions are:—length in mid-ventral line = about

[1] Branca-Festschrift, Leipzig, 1914, p. 235.
[2] Ann. S. Afr. Mus. vol. vii (1911) p. 309.

32 mm.; width=43 mm.; height=40 mm. In none of these vertebræ is the neural arch preserved.

Of the posterior cervicals (Pl. XIV, fig. 5) only the last four are complete, the five in front of these being represented by their arches only. The fact that these vertebræ are still articulated one with the other and are still partly embedded in matrix renders their description difficult; but it can be seen that the form of the articular surface is similar to that of the anterior cervicals described above. On the sides of the centrum the single rib-facets form well-marked prominences which occupy rather more than half the length of the centrum, and are situated nearer the posterior than the anterior border. Beneath them on each side of the middle line there is a depression into which a vascular foramen opens; these depressions are separated by a well-marked rounded hæmal ridge. The borders of the centra are raised into fine rugosities running at right angles to the articular faces. The length of the centra is less than the length or width, and the width is greater than the height.

The form of the thoracic vertebræ seems to be much like that of the centra of the posterior cervicals, but doubtless there is a transition to the condition seen in the dorsals. In these the ventral surface becomes rounded from side to side, the hæmal ridge disappearing. The ventral surface of the centrum is perforated near the middle line by a pair of small vascular foramina, and there is another larger pair situated about a third of the way up the sides. The articular surfaces are evenly concave, wanting the convex border seen in the cervicals, so that there is a sharp edge between the articular surface and the sides of the centrum which are strongly concave from before backwards. The dimensions of a dorsal centrum are:—length = 31 mm.; width=55 mm.; height=48 mm.

In the posterior cervical and thoracic regions the neural arches are large and massive. In the last two cervicals the base of the pedicle is produced into a short process which extends down to the costal facet, but does not seem to have reached the rib: in the next four vertebræ (thoracic) this process of the arch increases in size, and forms more and more of the rib-articulation until in the first dorsal it wholly supports it, becoming a prominent diapophysis (*d.*). This is compressed from before backwards, and is enlarged towards its outer end, which bears a somewhat convex facet considerably higher than wide. Followed back in the series, the dorsal rib-facets become smaller, and their vertical and horizontal diameters more nearly equal.

In the posterior cervical and thoracic regions the zygapophyses are large, and their articular surfaces are flat (making an angle of about 45° with the median plane). They project so far anteriorly and posteriorly that, when they were in articulation one with the other, there must have been a small interval between the articular surfaces of the centra. This interval is, in fact, shown in this specimen, and it can be seen that it was partly occupied by a disc

of hard substance which under the microscope seems to show some resemblance to calcified cartilage. There does not seem to be any question of epiphyses on the ends of each centrum, but merely of a simple intervertebral disc (Pl. XIV, fig. 5, *i.v.d.*). Possibly the large size and prominence of the zygapophyses, the convexity of the outer rim of the articular surface of the centra, and the presence of this disc may be connected with increased flexibility in some directions of this region of the column. In the dorsal region the thickened rounded border of the articular surface is wanting, and the concavity begins at the edge which is sharply defined, also the zygapophyses are smaller and less prominent: here the successive centra must have been in direct contact, and the degree of flexibility consequently much less. The neural spines of the cervical region are rather short, and curve backwards; the convexity of their anterior border is greater than the concavity of the posterior, so that they narrow towards their apex, which is occupied by a deep pit, probably marking the position of a cartilaginous extension in life. Towards the dorsal region the neural spines (*n.sp.*) lengthen somewhat, become more upright, and are of nearly the same width throughout their length.

The cervical and thoracic vertebræ are specially valuable for comparison with those of other Plesiosaurs, since in very many cases the skull and other characteristic portions of the skeleton are unknown. The most notable character of these vertebræ in the species now described is the form of their articular surfaces. A similar type of vertebra occurs in *Plesiosaurus capensis* Andrews, *P. degenhardti* Koken, *P. bernardi* Owen, *Cimoliosaurus valdensis* Lydekker, and in *Brancasaurus brancai* Wegner; also to some degree in *Plesiosaurus arcuatus* Owen. *Plesiosaurus degenhardti* is, however, distinguished from this species by the possession of cervical centra which are higher than wide, neural spines with their anterior and posterior borders parallel, and relatively small zygapophyses. In *P. degenhardti*, if the length of the centrum be taken as 100, the width is 127, the height 152; in the specimen here described, if the length be taken as 100, the width is 155, the height 146.

Comparison with the cervical of the type-specimen of *Cimoliosaurus valdensis* Lydekker[1] shows that the form now described resembled that species in the shape of its neural spine, but differed in several other respects. Thus, in *C. valdensis* the zygapophyses are relatively smaller and less prominent, and their articular faces are more nearly horizontal. The articular ends of the centrum are more nearly circular, and their central concavity (though deep) has not the sharply-defined central depression. In *Cimoliosaurus bernardi* the articular ends of the cervicals are deeply concave with a convex outer border, but here also the sharply-defined central depression is wanting; in this species, too, there is a strongly-marked oblique ridge running up the side of the arch from

[1] Cat. Foss. Rept. Brit. Mus. pt. ii (1889) p. 188, fig. 61.

the anterior angle of the pedicle to the posterior zygapophysis, a ridge which is wanting in our specimen.

Comparison with the vertebræ of *Plesiosaurus capensis* Andrews,[1] from probably the nearly contemporary beds of Uitenhage (Cape Province), shows very considerable similarity in several respects. The form of the neural spines in the posterior cervical and thoracic vertebræ is nearly the same; the articular face of the centrum has the same sudden depression of its middle portion; the zygapophyses in both are large, and project considerably in front of and behind the articular surfaces. The proportions of the centra are almost the same: thus if, as already mentioned above, the length of the centrum in the new specimen be taken as 100, the width will be represented roughly as 155, the height as 146. In *P. capensis*, under the same conditions, the width would be 156, the height 138. Differences in the skull, apart from other considerations, make it very unlikely that the specimen here described is specifically identical with the South African species.

Brancasaurus brancai Wegner is by far the best known of the Wealden Plesiosaurs, most of the skeleton having been described and figured.[2] The vertebræ resemble to a considerable degree those described above, the neural spines and the articular surfaces of the centra being very similar. On the other hand, the length of the cervical centra is greater in proportion to their width and especially to their height; the proportions are:—length=100, width=140, height=112. Other differences in the skull and shoulder-girdle are mentioned elsewhere (pp. 288, 296).

The shoulder-girdle (Pl. XV, figs. 1–3) is in a remarkable state of preservation, the bones, even the thin clavicular arch, being quite undistorted. Some parts of the bones are wanting; but the remaining portions being retained in their original positions in the matrix, it has been possible to fill up the gaps, and to restore accurately the original form of the various elements.

The general form of the shoulder-girdle will be best understood from the figures. It will be seen that the coracoids (*cor.*) are long and narrow. Opposite the glenoid and scapular surfaces they are thickened, the thickening extending to their median border, where it ends in a symphysial surface, convex longitudinally above and concave in the same direction below. The glenoid (*gl.*) surface, which forms about two-thirds of the articular surface for the humerus, is nearly flat, and makes an angle of about 120° with the facet for the scapula. The post-symphysial portion of the coracoids is thin, and in this region they must have been separated by a short interval in the middle line. The thin inner border of the left coracoid just behind the symphysis is cut into by a notch with a thin sharply-defined border: this notch seems to represent the

[1] Ann. S. Afr. Mus. vol. vii (1911) p. 309.
[2] Branca-Festschrift, Leipzig, 1914, p. 235.

foramen often seen between the coracoids in this position.[1] Posteriorly the coracoids widen little, but do not seem to have been produced outwards into postero-lateral processes. In front of the surface for the scapula the sharp border of the bone describes nearly a semicircle, of which the anterior end forms the somewhat inwardly projecting angle of the long narrow anterior prolongations of the bone. The symphysial union seems to have been continued to the slightly-expanded anterior end of these prolongations. There is no evidence that there was any anterior union of the median processes with the scapulæ, but there probably was one with the posterior processes of the clavicles.

The scapula (*sc.*) is much thickened at its posterior end where it bears the surface for union with the coracoid, and also that forming the upper third of the glenoid surface. These two surfaces meet at an angle of about 95°. In front of this thickening the ventral ramus of the bone first narrows, and then widens out into a broad plate; the outer border of this is straight, the inner concave, the antero-internal angle being produced inwards to a rounded point, which however did not reach the anterior prolongation of the coracoid or the corresponding expansion of the opposite scapula, as happens in the Elasmosauridæ. There was consequently no closed scapulo-coracoid fenestra. The ventral face of the inferior ramus of the scapula is concave, both from side to side and from before backwards. The base of the dorsal ramus of the scapula arises as a high plate of bone from the upper surface of the anterior two-thirds of the ventral ramus, into which it passes by a gentle curve on its outer side; while on the inner the curve is much sharper, especially towards the anterior end, the shelf-like surface thus formed supporting the similarly curved outer end of the clavicle which fits closely against it. The upper limb of the dorsal ramus forms a narrow backwardly directed blade of bone, narrowing towards its upper end: its upper edge is thin and sharp, the lower somewhat thickened and rounded.

The interclavicle (*i.cl.*) is a transversely elongated plate of bone, the upper surface of which is gently concave, as also is its anterior border. It is widest in the middle line, and terminates laterally in blunt points. Its postero-lateral borders interlock with the anterior borders of the clavicles in a close suture: there may have been a notch or foramen in the interclavicle near its hinder end, at, or a little in front of, the point where the clavicles meet, but the bone is incomplete in this region. Such a foramen is seen in the clavicular arch (B.M. R. 1322) of a Liassic Plesiosaur referred by Lydekker to *Thaumatosaurus megacephalus*[2] (see text-figure, p. 295).

The clavicles (*cl.*) are rather large bones, the form of which is shown in the figure. Their anterior borders interlock with the

[1] For instance, in *Cryptocleidus*: see C. W. Andrews, Cat. Marine Rept. Oxford Clay (Brit. Mus.) pt. i, 1910, p. 180, where it is suggested that it probably transmitted a blood-vessel.

[2] This is referred below to the new genus *Eurycleidus*.

posterior border of the interclavicle, behind which they seem to have met in a median suture. Their thin posterior edge is strongly concave; towards their outer ends they become thickened and bent sharply upwards, the convex surface thus produced fitting closely into the shelf-like projection on the inner side of the scapula (as described above). Apparently the posterior ends of the united clavicles overlapped the upper surface of the anterior ends of the forward prolongations of the coracoids, thus closing a large fenestra bounded by the coracoids, scapula, and clavicles.

The dimensions of this shoulder-girdle (in millimetres) are as follows:—

Greatest length of the whole girdle as mounted		426
Width of the same at the glenoid cavity		278
Coracoid.		
Greatest length		332
Width at the glenoid prominence		153
Least width of anterior prolongations		30
Width of anterior ends of the same		45
Length of glenoid facet	about	70
Depth of the same		37
Length of scapular facet		39
Greatest depth of symphysial surface	about	28
Scapula.		
Greatest length of ventral ramus		150
Width of the proximal end		61
Width of neck	about	37
Length of the upper border of the dorsal ramus		193
Greatest width of the anterior border of the ventral ramus		81
Clavicular arch.		
Greatest width of the arch as a whole		218
Antero-posterior length of the same in the middle line	about	125
Width of interclavicle	about	140
Greatest width of left clavicle		135

This type of shoulder-girdle seems to be a primitive one, being very similar to that of a girdle from the Lower Lias of Street (Somerset) which is represented in the text-figure (B, p. 295). This is part of the type-specimen of *Plesiosaurus arcuatus*,[1] figured in Hawkins's 'Sea-Dragons' (1834) and described in part by Richard Owen in the British Association Report on Fossil Reptiles for 1839 (1840) p. 76. This skeleton, which is in the British Museum (Natural History), was registered under several numbers (2028*–29*, R. 1317–18), and it is only recently that the bones of the shoulder-girdle have been developed and mounted with the advice of Prof. D. M. S. Watson. As now figured (text-fig. B), it is one of the best specimens of the shoulder-girdle of a Liassic Plesiosaur known. The clavicular arch has already been described and figured in detail by H. G. Seeley.[2] In its general structure it is very similar to that described above; but the interclavicle (*i.cl.*) is wider, and the concavity of its anterior border

[1] Referred below to the new genus *Eurycleidus*.
[2] Proc. Roy. Soc. vol. li (1892) pp. 128–30 & text-figs. 2–3.

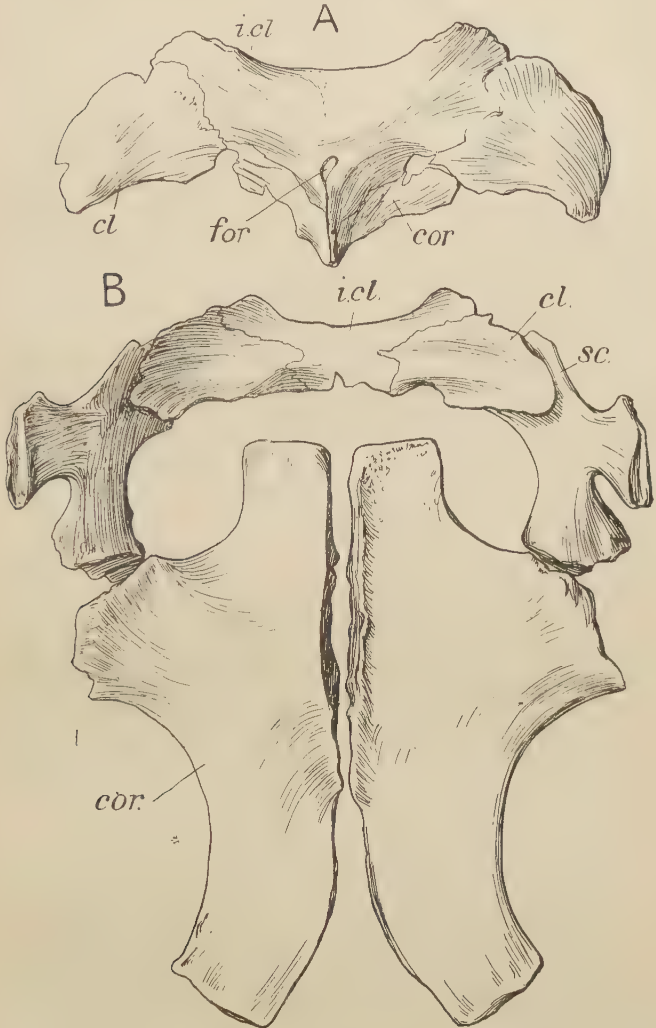
is more marked. There is a trace of the anterior border of a foramen in the posterior prolongation, most of which however has been broken away. The clavicles (*cl.*) interlock with the interclavicle in a complex overlapping suture (see Seeley's figure). Posteriorly they are crushed and incomplete, and so it cannot be seen whether they met in the middle line or extended back to overlap the coracoids. In the very similar but more complete clavicular arch ascribed by Lydekker to *Thaumatosaurus megacephalus*[1] and referred to above, the posterior portions of the clavicle and interclavicle are much more complete (text-fig. A, p. 295). Here it can be seen that the interclavicle (*i.cl.*) is prolonged backwards into a bifurcated process, enclosing a foramen or notch (*for.*). The clavicles (*cl.*) overlap on to the ventral face of this prolongation, and appear to meet below it in the middle line, extending behind it. If the coracoids in this Plesiosaur were similar to those of *P. arcuatus*, the clavicles must have overlapped the upper surface of their anterior prolongations, thus enclosing a fenestra as in the specimen here described.

The scapula in *P. arcuatus* is generally similar in form and in its relation to the clavicular arch, but differs in details from the Wealden specimen: the ascending ramus is much stouter, and widens instead of narrowing towards its upper end, which is occupied by a surface for a supra-scapular cartilage. The anterior portion of the ventral ramus does not widen out to the same extent; its inner face against which the clavicle fits is gently curved, and slopes downwards instead of forming a sharply angulated shelf. The coracoids of *P. arcuatus* differ in having their anterior prolongations much broader and shorter. Behind the thickened symphysial surface in the interglenoid region the median borders of the coracoids, instead of having their sharp edges separated by a considerable interval, were fringed with cartilages which must have met in the middle line. In *Brancasaurus* also they are separated for a considerable distance behind the symphysis, but unite posteriorly at the postero-internal angles.

Lydekker has referred both the reptiles originally described as *Plesiosaurus arcuatus* and *P. megacephalus*, to H. von Meyer's genus *Thaumatosaurus*, without any apparent justification. This genus was founded on some imperfect dorsal and cervical centra, some fragments of jaw with broken teeth, and some pieces of rib from the Great Oolite of Würtemberg. Nothing is known of the structure of the skull, shoulder-girdle, or pelvis; and it is exceedingly improbable that the Lower Liassic species above mentioned are referable to it. It seems better, therefore, that those Liassic species possessing the type of shoulder-girdle described above, as also a double costal facet on the cervical vertebræ in the centra of which there is no sharply-defined central concavity, should be referred to a new genus, for which the name *Eurycleidus* may be suggested, the type species being *E. arcuatus*.

[1] See Cat. Foss. Rept. Brit. Mus. pt. ii (1889) p. 167.

The Wealden species that forms the subject of this paper, while possessing a shoulder-girdle of similar type, has single costal facets and a deep central depression in the cervical centra; this may



A = Clavicular arch of *Eurycleidus megacephalus* (Stutchbury) from below, about a sixth of the natural size. (B.M. R. 1322.)

B = Shoulder-girdle of *Eurycleidus arcuatus* (Owen) from above, about a sixth of the natural size. (B.M. 2028*–29*, R. 1317–18.)

cl. = clavicle; *cor.* = coracoid; *for.* = foramen or notch in the interclavicle; *i. cl.* = interclavicle; *sc.* = scapula.

be referred to a second genus, *Leptocleidus*, its specific name being *Leptocleidus superstes*. Probably *Plesiosaurus capensis* is also referable to this genus.

The relationship of *Leptocleidus* to the other Wealden genus *Brancasaurus*, if Wegner's account of the shoulder-girdle is correct, must be remote, since in the latter the scapulæ extend inwards and join the anterior prolongations of the coracoids so that the shoulder-girdle is of Elasmosaurian type: it seems, however, by no means impossible that Wegner's restoration of this region may be mistaken.

The dimensions of the shoulder-girdle of *Eurycleidus arcuatus* (in millimetres) are:—

Greatest length in the middle line	558
Coracoid.	
Length of coracoid	456
Width of coracoid at the glenoid cavity	211
Width of the anterior prolongations	87
Length of the glenoid surface	87
Scapula.	
Length of the body of the scapula	280
Length from the top of the dorsal ramus to the anterior end, about	244
Width of the middle of the dorsal blade	53
Clavicular arch.	
Greatest width	359
Width of the interclavicle about	261

The dimensions of the clavicular arch of *Eurycleidus megacephalus* (in millimetres) are:—

Greatest width	464
Width of the interclavicle	324
Length in the middle line	153

The humerus of *Leptocleidus* (Pl. XV, fig. 4) was much expanded distally, but seems to have articulated with the radius and ulna only. The anterior border of the bone is nearly straight, the posterior strongly concave. The upper surface is gently concave in the direction of the long axis, the ventral face being correspondingly convex. None of the other bones of the paddle are preserved.

The dimensions of the humerus (in millimetres) are:—

Length	245
Width of head	50
Width of upper end, with trochanter	62
Width of middle of shaft	60
Width of distal expansion	124

The chief interest of *Leptocleidus superstes* lies in the circumstance that, although of Wealden age, it has retained a very primitive type of structure of the shoulder-girdle, similar to that found in the Lower Liassic species *Eurycleidus arcuatus* and *E. megacephalus*. In all these the clavicular arch is large, and the ventral rami of the scapulæ remain widely separated in the middle line. This type of shoulder-girdle is probably a direct inheritance from the Triassic ancestors of the group. The tendency to the reduction of the clavicular arch and its functional replacement by the expansion of the scapulæ to form a median symphysis was

manifested very early, so that even in the Upper Liassic *Microcleidus homalospondylus* there already appears an Elasmosaurian shoulder-girdle of a type nearly as advanced as that found in *Cryptocleidus*, *Muræenosaurus*, etc. from the Oxford Clay: that is to say, the enlarged ventral rami of the scapulæ form a median symphysis continuous posteriorly with the symphysis of the coracoids, while the reduced clavicular arch has already become functionless or nearly so, and lies within and upon the anterior scapular expansion. The retention of the primitive condition in *Leptocleidus* (and probably in *Brancasaurus*, if, as seems likely, Wegner's interpretation of its shoulder-girdle is erroneous) may be a consequence of the freshwater, probably fluviatile, habitat of this Plesiosaur, which resulted in its leading a life sheltered from the great competition that seems to have resulted in more rapid evolution among the marine Plesiosaurs. A somewhat similar case occurs among the Cetacea, of which the freshwater Platanistidæ retain numerous primitive characters derived from their Squalodont ancestors. This circumstance H. Winge[1] explains as the consequence of their comparatively sheltered habitat in rivers and estuaries, where they evaded crowding-out by the higher Cetaceans. It must be admitted, however, that the clavicular arch is not reduced in all cases in the marine forms: for instance, in *Dolichorhynchops osborni* Williston, from the Niobrara Chalk of Kansas, the clavicles and interclavicle are of relatively large size, and the general structure of the shoulder-girdle is not unlike that of *Leptocleidus* although the form of the interclavicle is different. Possibly this Cretaceous species may have originated from a freshwater form, which had secondarily adopted a marine life at a comparatively late period.

The specimens described in this paper, which is published by the permission of the Trustees of the British Museum, are all preserved in the Geological Department of that institution.

EXPLANATION OF PLATES XIV & XV.

Leptocleidus superstes, gen. et sp. nov.

Plate XIV.

[All figures, except 5, are a third of the natural size.]

Fig. 1. Posterior portion of skull, lateral view.
2. The same, palatal view.
3. Centrum of an anterior cervical vertebra.
4. Centrum of a middle cervical vertebra.
5. Posterior cervical, thoracic, and anterior dorsal vertebræ. A quarter of the natural size.

[*col.*=columella; *d.*=diapophyses; *i.v.d.*=intervertebral disc; *mx.*=maxilla; *n.sp.*=neural spine; *oc.c.*=occipital condyle; *orb.*=orbit; *pal.*=palatine; *par.*=parietal; *pas.*=parasphenoid; *p.f.*=? prefrontal; *pin.*=pineal foramen; *p.i.v.*=posterior interpterygoid vacuities; *pt.*=pterygoid; *q.*=quadrate; *r.*=cervical rib; *sq.*=squamosal.]

[1] 'Udsigt over Hvalernes indbyrdes Slægtskab' Vidensk. Medd. Dansk Naturh. Foren. vol. lxx (1919) p. 104.

Plate XV.

[All figures are a quarter of the natural size.]

Fig. 1. Shoulder-girdle, from above.
2. The same, from the front.
3. The same, from the side.
4. Right humerus, from above.
5. Two middle ventral ribs.

[*cl.*=clavicle; *cor.*=coracoid; *for.*=opening bounded by scapula, coracoid, and clavicle; *f.*=notch or foramen in coracoid; *gl.*=glenoid cavity; *h.*=head of humerus; *i.cl.*=interclavicle; *sc.*=scapula; *tu.*=tuberosity of humerus.]

Discussion.

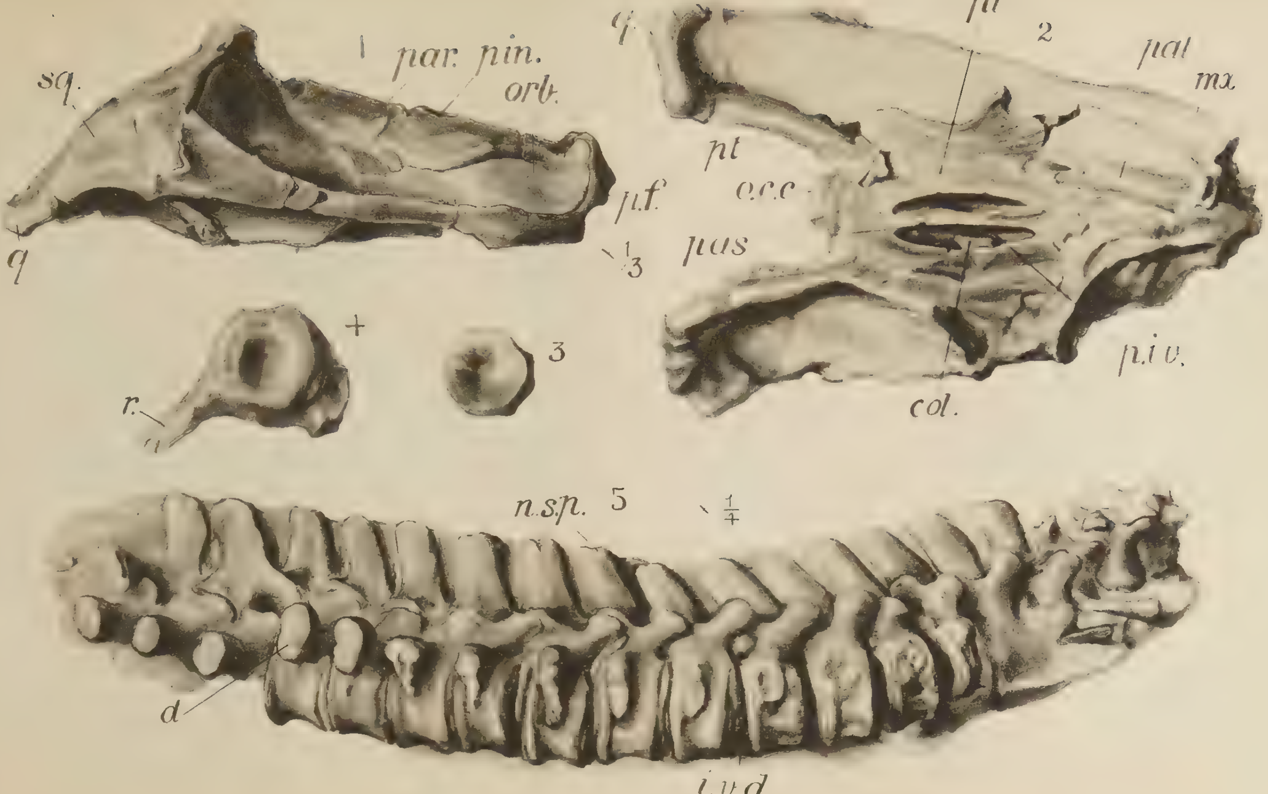
Dr. A. Smith Woodward referred to the interest of the section at Berwick, which shows the top of the Weald Clay and the base of the Lower Greensand. The Plesiosaur was found by Mr. Tooth in a well-defined layer of septarian nodules in the Weald Clay. The specimen was valuable, as showing the true shape of the clavicles and scapulæ: they were isolated in the nodule; but, when they were extricated and placed in contact, their curved surfaces fitted exactly. The neck was evidently more flexible than in the earlier Plesiosaurs. He agreed with the Author that the new specimen might be regarded as representing an ancient type, which owed its survival to its retreat to life in a river or lake.

Baron F. Nopcsa pointed out that in most groups of marine reptiles one can distinguish a long-necked and a short-necked series. Among the Lacertilia the short-necked forms are represented by the Aigialosauria and their descendants the Mosasauria, the long-necked by the Dolichosauria; of the Ichthyosauria, which are short-necked, the long-necked relatives seem to be the Mesosauria.

The President (Prof. A. C. Seward) referred to the close resemblance between the Wealden plants of Sussex and those found in the Uitenhage Series of the Cape Province, a resemblance that appears to be shown also by the reptilian remains from the two regions.

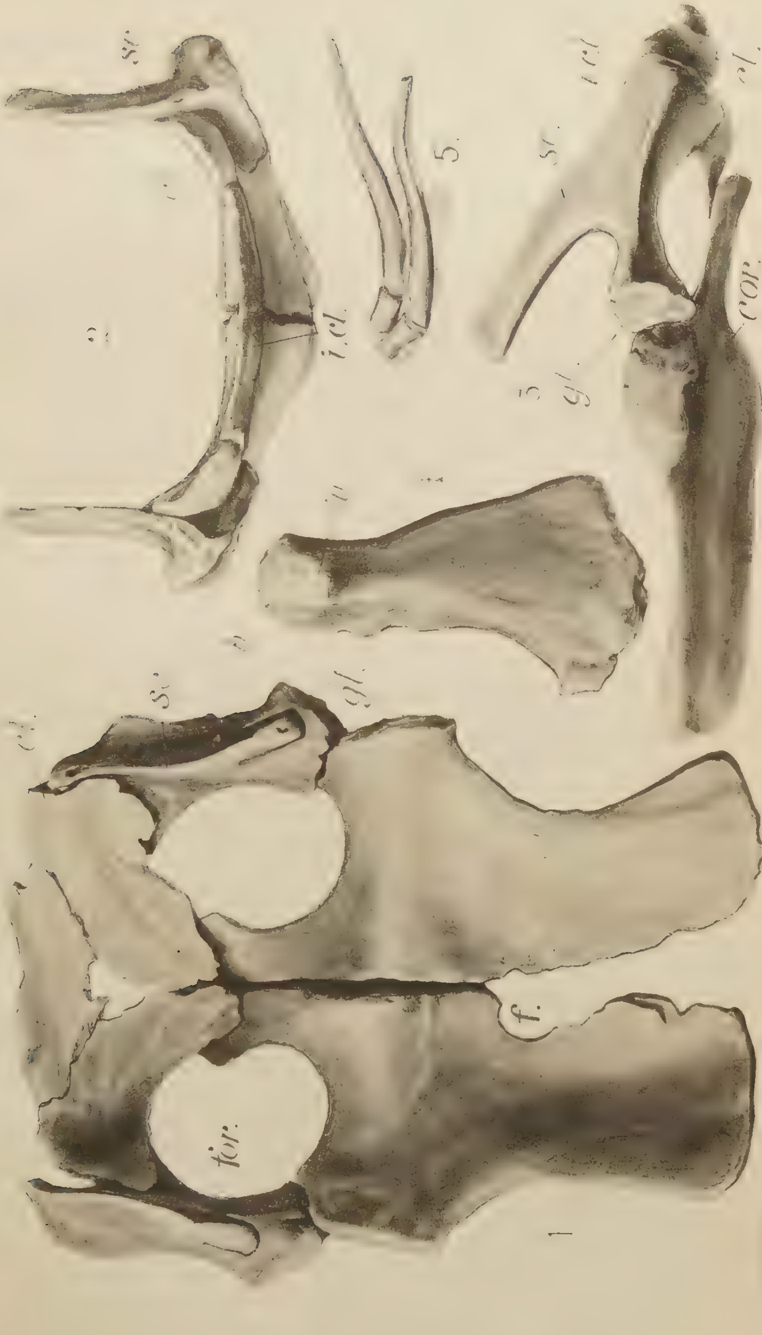
The Author expressed his thanks for the reception accorded to his paper.

[September 23rd, 1922.]



G.M.W. DEL.

LEPTOCLEIDUS SUPERSTES, gen. et sp. nov.



LEPTOCLEIDUS SUPERSTES, gen. et sp. nov.

M.W. del.

11. *The* Norite *of* Sierra Leone. By Frank Dixey, D.Sc., F.G.S. (Read June 22nd, 1921.)

[Plates XVI–XIX.]

Contents.

I. Introduction.

(1) General Remarks.

The norite of Freetown (Sierra Leone) was briefly described by G. Gürich[1] in 1887, and in 1918 Prof. S. J. Shand[2] translated Gürich's work, adding a few notes. I had the opportunity of making a detailed examination of this norite, as part of an investigation into the mineral resources of Sierra Leone; and in the course of this work it was found that the norite exposed around Freetown was only one end of a huge noritic complex which made up the whole

[1] 'Olivingabbro von Freetown (Sierra Leone)' Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxix (1887) p. 108; further reference to this paper will be made below, p. 305.

[2] 'The Norite of the Sierra Leone' Geol. Mag. 1918, p. 21.


Fig. I.
13° 10′
Bullom
Port Lokko Creek
C. Sierra Leone
8° 30′
ABERDEEN
MURRAY TOWN
FREETOWN
Mt. Aureol
WILBERFORCE
Havelock Plat.
Leicester Peak
LUMLEY
WELLINGTON
GODRICH
False Cape
Sugar Loaf Mountain
HASTINGS
DEVIL HOLE
SUSSEX
WATERLOO
2249
MACDONALD
YORK
Picket Hill
2912
ATLANTIC OCEAN
2701
JOHN OBEY
TUMBU
KENT
C. Shilling
8° N.
10′
8°
10′
Banana Is.
Geological Map
of the
SIERRA LEONE PENINSULA,
By F. Dixey.
[Based on W.D. Topographical Map No, G.S., G.S. 1764.]
Scale of Miles
0 1 2 3 4
Pleistocene & Recent Beds
Norite Complex
13° 10′ W

mountain-mass of the Colony.[1] Moreover, during the examination several features of considerable interest were observed, including the assimilation of one phase of the norite by another, the well-developed banding in the norite, the segregation of the iron-ores, and the sequence of the minor intrusions. These features, together with an important series of intergrowths of the common minerals, will be described in the course of this paper. The investigation into the mineral resources of the Colony, with especial reference to the iron-ores, formed part of the work of the Geological Survey of Sierra Leone during the latter part of 1918 and during 1919.

(2) Physiography of the Area.[2]

The Colony is a mountainous peninsula adjacent to the undulating low ground which forms the southern part of the Protectorate. Its mountains rise steeply from a narrow coastal plain to a height of nearly 3000 feet; this plain is continuous with that of the mainland, and is due to a Pleistocene uplift of a little over 300 feet.[3] It is made up of marine deposits derived largely from the denudation of the mountains. (See Pl. XVI, fig. 1.)

The mass of the Colony has been carved by erosion from an elongated stock of norite. As now exposed, the stock is 24 miles long and 8 miles wide, but it was doubtless much greater originally. From the southern end of the mass, the Banana Islands (forming a part of the same intrusion) extend away to the south-south-west. In the course of erosion a number of platforms have been carved into the mountain-mass. The more important of these platforms attain maximum altitudes of about 2400, 1800, and 1300 feet respectively; they can all be distinguished without difficulty from the summit of one of the higher peaks of the northern end of the Colony, such as Leicester Peak, and also from the sea a few miles west of Freetown Harbour. The highest platform can be seen at a level slightly below the summit of Sugarloaf Mountain (see Pl. XVI, fig. 1), the second slightly below that of Leicester Peak, while the third forms the high ground that encloses Freetown on the south-east, south, and south-west. The oldest platform forms the upper limit of the broad middle ridge that traverses the Colony from end to end, whereas the second platform is recognized principally in the even tops of the two lateral ridges that run parallel with the main ridge; the third platform can be traced at intervals around the flanks of the higher platforms. Several

[1] The term Colony refers to that part of Sierra Leone which lies along the coast; it forms principally a peninsula about 25 miles long and 9 miles wide. At the northern end of this peninsula is situated the port of Freetown. The remaining part of the country is known as the Protectorate; it extends inland for a considerable distance, and covers an area almost as large as Ireland.

[2] See also F. Dixey, 'The Physiography of Sierra Leone' Geogr. Journ. vol. lx (1922) p. 41.

[3] See F. Dixey, 'Pleistocene Movements in Sierra Leone' Trans. Geol. Soc. S. Africa, vol. xxii (1920) p. 112.

smaller platforms can be recognized at intermediate and at lower levels; those at the lower levels correspond in height to low flat-topped hills and ridges that occur in neighbouring parts of the Protectorate.

Erosion of another type has given the stock a deeply-incised drainage-system which is remarkable for its regularity and simplicity (see map, fig. 1, p. 300). The principal watersheds are the three parallel ridges which traverse the Colony from end to end, and two groups of spurs which spread fan-wise from each end of the mountain-mass; the ridges throw off at right angles a number of short spurs which, on the northern side at least, are of very regular form. This arrangement is probably due to the fact that the master-joints of the stock are parallel and transverse to its length in the middle portion, but radial at the ends; and, as the original covering was denuded, the young streams discovered these lines of weakness and developed along them. Many bold cliffs and joint-faces rising out of the dense bush extend along the sides of the main and the tributary valleys.

(3) Size and Form of the Occurrence.

The Sierra-Leone norite is remarkable in being the largest intrusion of norite of which I have been able to trace any record. Elsewhere, however, norite is well known to occur in intimate association with other rocks which form intrusions of enormous size. The norite of Sierra Leone is further remarkable in that it occurs as a stock which, regarded as a basic stock, is of very considerable size. Most of the known greater basic and ultrabasic masses, with the exception of certain anorthosites, occur not as stocks, but rather in the form of enormous laccolites and sills: as, for example, the Bushveldt,[1] Insizwa,[2] and Sudbury[3] intrusions. Both as a basic mass and as a norite-mass, the Sierra-Leone norite is far more considerable than any of the British occurrences.[4]

It is worthy of notice that, so far as can be observed, the Sierra-Leone norite as a whole shows neither a marginal nor a stratiform structure; and further, that it is isolated from all other igneous rocks, apart from the dolerite-dykes and the small veins of norite-aplite which traverse it. In these respects it differs considerably from the important basic masses already mentioned: the Bushveldt, Insizwa, Sudbury, and many other great laccolites and sills exhibit a stratiform arrangement ascribed to the control of differentiation

[1] G. A. F. Molengraaff, 'Géologie de la République Sud-Africaine du Transvaal' Bull. Soc. Géol. France, ser. 4, vol. i (1901) p. 62.

[2] A. L. Du Toit, 'Report on the Copper-Nickel Deposits of the Insizwa, &c.' 15th Ann. Rep. Geol. Comm. Cape of Good Hope (1910) p. 111.

[3] A. E. Barlow, 'Nickel & Copper Deposits of the Sudbury Mining District' Ann. Rep. Geol. Surv. Canada, vol. xiv, pt. H (1904).

[4] Note, however, that certain norites recently described from the neighbourhood of Huntly in Aberdeenshire attain a considerable size—*teste* H. H. Read, in 'The Contaminated Magmas of Aberdeenshire' (paper read to Sect. C, Brit. Assoc., Edinburgh, 1921).

by gravity, while others show a similar arrangement due to successive intrusions, as exemplified by the basic and ultrabasic Tertiary igneous rocks of Rum.[1]

Other norites, such as those associated with the Galloway masses,[2] occur as basic phases of granitic intrusions; while yet others, such as those of St. David's Head,[3] form one member of a series that comprises a wide range of rock-types. The norite which we are now considering possibly possessed a marginal phase, long since swept away; but it never had any stratiform arrangement, unless it was originally very extensive as compared with its present size. The following observations on the specific gravity of the norite, ranging from sea-level to the summit of the highest peak (an altitude of nearly 3000 feet), indicate great irregularity of structure.

Locality.	*Approximate elevation, in feet.*	*Specific. gravity.*
1. Landing-stage, Murray Town	0	3·06
2. Banana Islands	0	3·17
3. Foot of Charlotte Falls	400	3·23
4. Sand Elevator	500	2·99
5. Wilberforce	700	2·95
6. Waterloo–York road	1000	3·26
7. Leicester Peak	1400	2·87
8. Leicester Peak	1950	2·98
9. Picket Hill	2900	2·80
Average of twelve specimens		3·01

Numerous observations on mineralogical composition yield a similar result. Nevertheless, in the variety and sometimes the succession of its associated minor intrusions, the norite bears a strong resemblance to certain other basic masses, such as the norites of St. David's Head, the Duluth laccolite,[4] and the gabbro of the Cuillin Hills.[5]

(4) The Intrusions.

The stock is thus made up essentially of a noritic intrusion of fairly uniform character. But the original mass was invaded in quick succession by several cognate sub-magmas, all of which were, however, relatively of very small volume; at a later date the complex was cut by numerous dykes of enstatite-dolerite. Most of these rocks are well exposed along the south-western foreshore

[1] 'Geology of the Small Isles of Inverness' Mem. Geol. Surv. Scot. 1908, p. 68.

[2] 'The Silurian Rocks of Scotland' Mem. Geol. Surv. 1899, p. 613.

[3] J. V. Elsden, 'The St. David's Head Rock Series' Q. J. G. S. vol. lxiv (1908) p. 273.

[4] M. L. Nebel, 'The Basal Phases of the Duluth Gabbro near Gabamichigami Lake (Minnesota), & its Contact-Effects' Econ. Geol. vol. xiv (1919) p. 367. See also N. H. Winchell on this intrusion in Final Rep. Geol. Surv. Minnesota, vols. iv & v (1899–1900).

[5] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 82.

of the Colony; inland, where the bush is very dense, they rarely crop out elsewhere than in stream-beds and as joint-faces along the sides of valleys. The various rock-types will be described below in their order of intrusion, namely:—

(i) Older or normal norite.
(ii) Younger norites and norite-pegmatite.
(iii) Beerbachite.
(iv) Norite-aplite.
(v) Dolerite.

(5) Age of the Rocks.

Although no field evidence has been found to throw any certain light upon the age of the complex, there are many considerations of a general character which indicate that, while probably later than pre-Cambrian, it is nevertheless of very great age. The only rocks seen in contact with the complex are the Pleistocene sediments which rest upon it on all sides, and the nearest rocks of an earlier age than these are representatives of an ancient series of crystalline schists and gneisses which are exposed in the Port Lokko Creek, 11 miles east-north-east of the north-western end of the norite-complex. Since the complex is elongated in a direction parallel with the general trend of the coast of this part of West Africa, it is obvious that few, if any, rocks will be exposed on the strike, or on the seaward side, of the complex. The only crystalline rock known to occur actually on the strike of the complex is the nepheline-syenite of the Los Islands, situated off the coast of French Guinea at a distance of 72 miles from Freetown; it is important to notice, however, that the mainland opposite the Los Islands consists of a series of diabases, gabbros, and peridotites intruded into ancient crystalline schists.[1] In the Protectorate of Sierra Leone, crystalline rocks approach the strike of the complex in the locality already mentioned, and also in the mainland off the north-eastern corner of Sherbro Island. Thus it is seen that all the old rocks exposed on the strike, and on the landward side, of the norite, over a large area extending from Liberia to the Los Islands, belong to an ancient series of crystalline schists and gneisses generally considered to be of pre-Cambrian age.[2] The following considerations show that the

[1] A. Lacroix, 'Les Syénites Néphéliniques de l'Archipel de Los' Nouv. Arch. Mus. Hist. Nat. Paris, ser. 5, vol. iii (1911) p. 108. Note, moreover, that along the coast of Liberia there are at least four masses of gabbro and associated basic rocks which are largely similar in occurrence to the norite of Sierra Leone, but of smaller size. See also H. Hubert, 'Carte Géologique de l'Afrique Occidentale' 1920, and Delafosse, 'Le Libéria en 1907' pt. ix: Géologie, Bull. Com. Afrique Franç. 1907, No. 12.

[2] See A. E. Kitson, 'The Gold Coast: some Considerations of its Structure, People, & Natural History' Geogr. Journ. vol. xlviii (1916) p. 377; *id.* 'Outlines of the Geology of Southern Nigeria (British West Africa), with especial reference to the Tertiary Deposits' Abs. Proc. Geol. Soc. 1918–19, pp. 100–105. Also J. D. Falconer, 'The Geology & Geography of Northern Nigeria' 1911, and 'The Geology of the Plateau Tin-Fields' Bull. No. 1, Geol. Surv. Nigeria (1921) p. 33.

norite-complex itself, while probably later than pre-Cambrian, is nevertheless of very great age [1]:—

(1) The complex as a whole is unfoliated, although half-enclosed by highly-foliated crystalline rocks.

(2) The complex is elongated parallel to

(a) The foliation of the crystalline rocks [2];

(b) to the general trend of the coastline; since, however, there is good reason to suppose that the present coastline was determined by a series of important more or less parallel faults, it is probable that the complex originated as an intrusion along a considerable fault running parallel with the foliation of the crystalline rocks.

(3) In its great size, its highly-magnesian character (resulting in the frequent development of rhombic pyroxenes), and the extraordinary freshness of its constituent minerals, it presents a close analogy with the Charnockite Series of India,[3] certain phases of the anorthosites of Canada,[4] the Scandinavian norites, and other well-known intrusives all considered to be of pre-Cambrian age.

(4) The enormous amount of erosion undergone by the norite and the rocks into which it intruded must have required a very long period of geological time in which to take place. For instance, the complex, which despite erosion is even now exposed to a depth of 3000 feet, must have been covered at the time of its intrusion by a thickness of many thousands of feet of sediments or other rocks, all of which have now completely disappeared. Also, within a radius of 70 miles on the landward side of the complex the only rocks so far observed to rise above the low-lying Pleistocene sediments are the crystalline schists. These schists, which rarely attain a height of more than 700 feet above sea-level, were invaded by gneissose granites such as now, on account of their superior resisting powers, make up the high land forming the north-eastern part of the Protectorate. But even these hard granites, which have been carved into a series of plateaux one above the other, do not in general attain a height of more than 2000 feet above sea-level anywhere within 130 miles of the isolated complex. Finally, certain of the extensive platforms carved into the ancient crystalline masses have their counterparts on the norite-complex (see above, p. 301); one of these platforms of the Protectorate, standing at a height of about 1200 feet, supports a thickness of nearly 700 feet of (?) early Palæozoic sediments, which even now are practically horizontal.[5] Thus it is seen that the erosion of the complex and the surrounding rocks must have been very great indeed.

It may be noticed at this point that Gürich, in the paper cited above (p. 299), concluded that the norite was considerably younger than the pre-Cambrian. This conclusion, however, was based on several errors of observation: for instance, he failed to distinguish the laterite formed by alteration of the Pleistocene sediments from that derived from the norite by lateritization in place (see below, p. 321), and, further, he regarded both of them as volcanic rocks or tuffs. He was, nevertheless, fairly well acquainted with laterite, as we know it, from many parts of the West Coast. In consequence of this confusion he considered the norite to be a laccolitic intrusion into the 'tuffs,'

[1] It is proposed to give additional evidence as to the great age of the complex, based upon certain important relations existing between the norite and the large basic intrusions of French Guinea (referred to below) in a subsequent paper on the geology of Sierra Leone.

[2] F. Dixey, Rep. Geol. Surv. Sierra Leone, 1919, p. 8; also *ibid.* 1920.

[3] T. H. Holland, Mem. Geol. Surv. India, vol. xxviii (1900) p. 119.

[4] A. Lawson, Amer. Geologist, vol. vii (1891) p. 153.

[5] F. Dixey, Rep. Geol. Surv. Sierra Leone, 1920.

and, where certain bands of the norite were deeply lateritized at their outcrop while neighbouring bands were practically unaltered, he concluded that the norite had locally forced its way along the bedding of the 'tuffs' in the form of small sills. Finally, since the crystalline schists of pre-Cambrian age would probably be steeply inclined if at all present in the country, whereas the 'tuffs' were horizontally bedded and were presumably 'younger' than the schists, therefore the norite itself, 'younger' than the 'tuffs,' must necessarily be much later than pre-Cambrian in age. Gürich considered these conclusions to be supported by analogy with the conditions prevailing in the Los Islands.

(6) Relation to other West African Basic Rocks, and also to a West African Magnesian Province.

Two great petrographic groups, both made up of rocks rich in hypersthene, are known[1] to exist in West Africa; they consist respectively of a series of peridotites, gabbros, and diabases occurring principally in French Guinea, and of a series ranging from norites to hypersthene-granites, which has been compared by Prof. Lacroix with the Charnockite Series of India. The peridotites of the first series approach wehrlite in composition, and consist mainly of olivine with a little diallage. The diabases include types rich in olivine, hypersthene, and a monoclinic magnesian pyroxene respectively. The gabbros form the most important group, and they occur in large masses: they consist of felspars ranging from labradorite to bytownite, diallage, and small quantities of a magnesian pyroxene (pigeonite); hypersthene and olivine occur in variable amounts. The felspars are free from zoning, and show a tendency to parallelism; the structure approaches an ophitic character. These gabbros show varieties approaching towards norite and troctolite respectively; but, so far, actual examples of these types are not known in French Guinea. From the limited information available at the time when he wrote, Prof. Lacroix considered that the rocks around Freetown were similar to these gabbros; and it is interesting to note that the present investigation not only confirms this similarity, but goes to show that the Sierra-Leone norite is probably part of the same great basic series.

The other great series, analogous to the Charnockite Series, was considered by Lacroix to occur almost exclusively on the Ivory Coast; but from recent Survey work in the Sierra-Leone Protectorate it appears that rocks similar to these are well developed among the old crystalline schists in this area also.[2] The Sierra-Leone norite, however, differs considerably from this series, notably in the absence of granular structure, in the absence of quartz, and in the abundance of olivine and augite. These mineralogical differences are expressed chemically to some extent in that the Sierra-

[1] A. Lacroix, 'Les Syénites Néphéliniques de l'Archipel de Los' Nouv. Arch. Mus. Hist. Nat. Paris, ser. 5, vol. iii (1911) p. 108; *id.* 'Sur l'Existence à la Côte d'Ivoire d'une Série Pétrographique comparable à celle de la Charnockite' C. R. Acad. Sci. Paris, vol. cl (1910) p. 18.

[2] F. Dixey, Reps. Geol. Surv. Sierra Leone, 1920–21.

Leone norite is poorer in alkalies, generally in silica, and richer in magnesia and lime.

Not the least interesting feature concerning the study of the Sierra-Leone rocks of both the Colony and the Protectorate is that they tend to confirm Lacroix's statement as to the widespread occurrence in West Africa of rocks rich in magnesium. This richness in magnesium, which generally gives rise to more or less abundant hypersthene,[1] leads to the conception of a West African Magnesian Province.[2]

II. Field Observations.

(1) The Older or Normal Norite.

The oldest and most important member of the series is a norite of medium texture, which in succeeding paragraphs will be defined as the normal norite. It varies but little in composition, texture, and macroscopic characters from one end of the Colony to the other. It consists essentially of a plagioclase (labradorite), augite, and a rhombic pyroxene, with varying proportions of olivine; iron-ore and apatite occur in small amount, and are unevenly distributed. An analysis of a single specimen of this rock has given the following result:—

	Per cent.
Silica	48·25
Alumina	21·54
Ferric Oxide	3·59
Ferrous Oxide	3·60
Manganous Oxide	0·45
Lime	9·73
Magnesia	6·30
Potash	1·60
Soda	1·76
Phosphoric acid	0·015
Titanic acid	0·26
Water above 105° C.	2·90
Total	99·99

Prof. S. J. Shand has classified the rock as a leucocratic olivine-norite (l_6—to l_9—subnorite).[3] The norite is tough and commonly grey in colour; with increasing iron content it becomes denser, harder, and splintery, gives a strong metallic ring when struck with the hammer, and weathers with a black lustrous surface.

[1] The formation of hypersthene will depend chiefly on the relative amounts in the magma of both alumina and lime; hypersthene would be unlikely to form until these oxides had been taken up by felspars and augite. A monoclinic magnesia-pyroxene may accompany and even replace hypersthene in the highly magnesian rocks: see A. Lacroix, Nouv. Arch. Mus. Hist. Nat. Paris, ser. 5, vol. iii (1911) p. 117, and also J. V. Elsden, 'The St. David's Head Rock Series' Q. J. G. S. vol. lxiv (1908) p. 288.

[2] See F. Dixey, 'The Magnesian Group of Igneous Rocks' Geol. Mag. 1921, p. 485.

[3] 'The Norite of the Sierra Leone' Geol. Mag. 1918, p. 23.

Sometimes it becomes granular, and its texture then approaches that of a coarse dolerite. The rock is characteristically banded, but to a variable degree, and it usually exhibits a parallelism of the felspars which is often obvious even when the banding is obscure. Finally, all minerals are beautifully preserved, in common with those of succeeding intrusions.

The banding of the norite occurs to a greater or less degree throughout the Peninsula, and is essentially a flow-banding produced during intrusion. Individual bands are generally constant in thickness, and their strike remains uniform over distances of several hundred yards; any contortion of the banding is quite exceptional, but it has been observed in one case around the margin of a pegmatite intrusion. The bands become more obvious with weathering, on account of varying resistance or colour: the colours of weathered bands range through dark-grey, brown, red-brown to almost black; whereas the slight differences in composition between one band and the next are but faintly indicated on a fresh surface.

Locally the fluxion-structure is more pronounced; individual crystals within the bands are broken down and rolled out, and the bands themselves, while keeping a more or less uniform strike, tend to form lenticles which sometimes thin out completely in about half a dozen yards. Some of the bands contain streaks and seams of magnetite, or of magnetite and felspar, ranging up to 3 inches in thickness. Where a marked difference in composition of neighbouring bands occurs, it is due to varying proportions of the felspathic and ferromagnesian constituents, leading in a few extreme instances to bands of coarse granular olivine. The bands vary in texture as well as in composition; the coarser of them are generally dark, and they thus bear a close resemblance to the coarse norite which was intruded at a slightly later date (see below, p. 310). The darker tinge of the coarse bands is seen in thin section to be due to the abundance of minute opaque inclusions in the felspars, as well as to the greater proportion of ferromagnesian constituents.

The relation between the banding and the separation of the constituents of the magma is clearly displayed at a point on the foreshore near No. 2 Town. The normal norite assumes a patchy character, due to the separation of the ferromagnesian constituents (chiefly pyroxenes); these constituents segregate into numerous dark clots, up to 2 inches in diameter, which remain enclosed in a pale felspathic matrix. Where movement occurred at a late stage, the clots are elongated or drawn out into more or less parallel streaks, and in some cases the structure can be seen to pass into regular banding of the characteristic type.

The banding of the Sierra-Leone norite is similar to, but better developed than, that observed in the St. David's-Head norite by Dr. J. V. Elsden.[1] A banding with many parallel

[1] 'The St. David's Head Rock Series (Pembrokeshire)' Q. J. G. S. vol. lxiv (1908) p. 277.

features has been noted also in the gabbro of the Cuillin Hills by Sir Archibald Geikie and Dr. A. Harker,[1] and in the Carrock-Fell gabbro by the latter.[2]

In many localities the grey surface of the norite shows numerous ill-defined brown and black spots: the former being composed of pyroxene and felspar in ophitic relation, and the latter of spongy growths of magnetite.

The principal intrusions into the normal rock are:—(1) the younger norites; (2) norite-pegmatite; (3) beerbachite; (4) norite-aplite; and (5) dolerite; but, in addition to these, there are two series of veins and a felspar-olivine rock, all, however, of relatively little importance. I may now briefly describe these smaller intrusions:—

The veins may be divided into two series, according to their age and occurrence.

(*a*) The veins of the first series occur in the older norite; they have ill-defined margins and a complex branching and tapering habit which causes them to weather into a rough network on an exposed surface. An example of this may be seen on the foreshore at Kent opposite the Court House. The veins rarely exceed 2 inches in width; they are generally less basic than the enclosing rock, and are of rare occurrence as compared with the veins of the later series. They closely resemble the segregation-veins figured and described in the Skye Memoir (p. 78).

(*b*) The veins of the second series are related in occurrence and in composition to the younger norites; they are consequently younger than those of the first series, and may sometimes be seen to cut them. They are distinguished from the segregation-veins by their composition, by the inclusion of ragged black bronzites measuring up to an inch in diameter, by their sharper margins, more regular form, and greater width.

The felspar-olivine intrusions consist of a tough pale-green rock of medium texture, rich in olivine and containing numerous small black grains of iron-ore. One of its best exposures is near the foot of Charlotte Falls, where it forms a small lenticle in the normal norite about 4 feet thick.

Exposures.

(i) Murray Town, foreshore.—Normal norite banded and spotted, and traversed by black pyroxenic veins.

(ii) Aberdeen Creek, foreshore.—Southern point: the norite is banded and highly ferruginous; it contains numerous seams rich in magnetite, and the laterite resting upon it is a good hæmatite-ore.

(iii) Sussex, foreshore.—Flow-banding well developed; some bands show crushed felspars, others consist largely of coarse granular olivine.

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[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 91.

[2] 'Carrock Fell; a Study in the Variation of Igneous Rock-Masses: Part I—The Gabbro' Q. J. G. S. vol. l (1894) p. 319.

(iv) Toke.—Both normal and coarse norite cut by pegmatite-veins up to 18 inches in width; normal norite pierced by fine siliceous veins.

(v) Kent, Cape Shilling, and Banana Islands.—Normal norite variably ferruginous; banding beautifully developed on the foreshore near the church at Kent.

(2 *a*) The Younger Norites and Norite-Pegmatite.

The younger norites form two or more series of intrusions cutting the older or normal norite; but they are collectively of small bulk, as compared with the original intrusion. In composition they differ little from the normal norite, and are distinguished principally by their texture, which is generally much coarser than that of the older rocks. There are, however, several other distinguishing features of great use in the field: when weathered, the younger norites are dark grey in colour, and possess a curious scaly surface. Moreover, since jointing is but slightly developed in them, their outcrops form large hummocks or well-rounded residual boulders. The older norite, on the other hand, becomes dull-red on exposure and, being well jointed, weathers into rectangular blocks with sharp edges and clean-cut surfaces. One other important point of difference remains: the normal norite is generally well-banded, whereas the younger norites are free from banding, although the felspars in them are often more or less parallel. (See Pl. XVI, fig. 2.)

When thin sections of the two rocks are compared, however, certain other differences are apparent: the coarser or younger norite is seen in most cases to be richer in hypersthene, in iron-ores, and in micrographic intergrowths of felspar and augite; whereas it is generally poorer in felspar and also in apatite. Moreover, the felspars of the coarser rock are slightly more basic, and the darker colour which they give to the hand-specimens is seen to be due to innumerable opaque inclusions of very small size.

A typical specimen of the younger norite consists essentially of grey sub-parallel felspars, dark-brown to black hypersthene, and a little granular augite, commonly diallage. The felspars are tabular in habit, and generally about 1 inch long. Olivine and magnetite are usually common: the former as rounded grains and sometimes as plates enclosing felspar-laths, and the latter both as grains and as interstitial growths. Locally, the magnetite forms lenticular streaks and abundant small masses ranging up to 2 inches in length. A partial analysis of a single specimen of this rock shows:—Silica 41·16 per cent., alumina 11·13, iron oxides 22·30, and magnesia 17·68. This norite also contains small brown and black patches, similar in some respects to those in the older rock, but more numerous. The black patches are pyroxenes in some cases, and spongy growths of magnetite in others. The brown patches are of two types which differ considerably in origin. Those of the first type are small and fairly evenly distributed, and they each consist of a rounded augite-crystal, typically about

an inch and a half in diameter; they enclose felspar-laths more or less completely, and this, in the case of the larger spots of this type, gives rise to a beautiful ophitic structure. The brown spots of the second type vary considerably in size, but they are generally larger and of finer texture than those of the first type; they are often irregular in shape, and of a reddish tinge. These patches are altered and highly-corroded fragments of the older norite, and are naturally most numerous near the margins of the parent rock; they were saved from complete destruction only by the freezing of the invading magma.

The younger norites formed several series of intrusions into the older norite, but only two of them, referred to below as the first and second series respectively, can be recognized with certainty. The first of these, much smaller in volume than the second, was intruded after the older mass had largely cooled down; consequently it shows a chilled margin in many cases. It generally possesses a texture similar to that of the main mass, but its characteristic colour and weathering, as well as the lack of banding and jointing, readily distinguish it from the normal norite. Like the intrusions of the later series, it generally broke through the older norite quite irregularly; nevertheless, cases do occur in which it took on the habit of the later dolerite-dykes and gave rise to a rock, which, in the hand-specimen, is distinguished from the coarser dolerites only with great difficulty. Fortunately, the relations of these rocks are made clear at several exposures wherein the dolerite is seen to cut all phases of the norite (see below, p. 317). The second and more important series is typically much coarser than the older or normal norite, and is consequently coarser than the first series also. Since the exposed portions of the second series are probably only the upper part of one or more very large intrusions, this greater coarseness may be due either to the greater volume and consequent greater capacity for heat and higher temperature of the second series, or even to the preliminary heating of the older norite by the first series. Either one of these causes would have enabled the second series to cool slowly, and thus acquire a coarser texture. It is at least certain that the second series contained an enormous reserve of heat, because to it is due most of the extensive alteration produced in the older norite. Another possible factor in producing the coarser texture was the slight difference in composition, such as induced an even greater degree of coarseness in the next set of intrusions, and caused them to crystallize as norite-pegmatite.

Norite-pegmatite cuts both the older and the younger norites, and takes the form of veins as much as 18 inches wide and irregular tongues several yards across: one of the latter has apparently induced foliation parallel to its margin in the older or normal norite enclosing it. The norite-pegmatite consists essentially of augite and bronzite, with some felspar and a small quantity of magnetite.

(2 *b*) Field Relations of the Older and Younger Norites.

Apart from several small isolated exposures on the mountains of the peninsula, the younger norites crop out only along the foreshore on the south-western side. They occur as numerous intrusions, many of them continuous under a thin roof of the invaded rock. These intrusions are of all sizes up to a quarter of a mile in length, and several of the larger ones form low capes, as for example, Godrich Point (see p. 313). They do not show any regular arrangement, except in one case, where four of them are elongated along a line running east and west. They send out numerous veins and tongues into the surrounding rocks. The grey rounded masses of the coarse or younger norite are in most cases readily distinguished from the well-jointed, dull-red blocks of the normal type. (See Pl. XVI, fig. 2.)

In certain places the junction of the older and younger norites can be followed for as much as 100 yards, and is seen to consist of a confused jumble, or intrusion-breccia, of the two types; it includes wide areas of the normal rock shattered and pierced by numerous veins and tongues of the younger norite, and also scattered blocks and fragments of the normal norite, some sharp and angular and others deeply corroded. Even where the junction is not so broad, it is often vague and difficult to follow because the older rock has in some places been heated to a high temperature and even re-fused. Away from the junction are a few isolated masses of younger norite and of older norite, the former representing cupolas of the main intrusion, and the latter the remains of pendants from the roof. Also, within the younger norite are stoped blocks of the older norite, some of them moved only slightly out of place, while others, carried a considerable distance, lie in all directions. Moreover, some present clean fresh joint-faces to the younger norite, and others show slight corrosion or deeply-indented outlines. Yet others, while retaining their form, have lost their original texture and composition; finally, many are completely shattered, and so permeated by the younger norite that they are represented by a mixed rock showing only shreds of the original norite. (See Pl. XVII, fig. 1.)

The invading magma nearly always cuts across the banding of the older mass, and only in exceptional cases does it appear to have induced any foliation. In these instances a few bands and numerous streaks are associated with and arranged parallel to the margins of the coarse intrusions, as if a gneiss, comparable in structure and origin with (α) the 'streaky' phase of the Kennack gneiss,[1] and (β) the gneisses of Rum,[2] had been formed by the intermixture of plastic fragments of the older norite with the viscous invading magma. This banding and streakiness is distinguished from the ordinary banding of the older norite by greater

[1] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 132.

[2] 'The Geology of the Small Isles of Inverness' Mem. Geol. Surv. Scot. 1908, p. 69.

differences in the texture of the component parts, and by the rough weathering and darker colour of the bands and streaks of the younger rock. Nevertheless, where relations between the different rocks are very complex, it is not always possible to assign the banding to one cause rather than to another.

Important Exposures.

(i) Godrich Point.—Four elongated domes of coarse norite, long axes running east and west, rise through a roof of normal norite. One of them, forming Godrich Point, cuts across the banding of the normal norite, and is itself pierced by a dolerite-dyke; another, 5 yards long and 3 yards wide, sends out a number of little tongues into the normal norite.

(ii) Point north of No. 2 Town.—Striking complex of coarse and normal norites displayed: blocks and fragments of normal norite measuring several feet across are enclosed within the coarse norite; a few of them are angular, with sharp boundaries, but the greater number show corroded outlines with large re-entrant curves. Many normal norite-fragments are small and ill-defined, and in some places are, with the enclosing rock, drawn out into wavy streaks. There are also several exposures of a rock of mixed texture due to permeation of normal norite by coarse norite.

(iii) Toke Point.—Intrusion phenomena well exposed.

(iv) York foreshore.—Large area of coarse norite richly impregnated with magnetite. In it are numerous stoped blocks of normal norite measuring as much as 10 yards in diameter; they exhibit all stages of disruption, corrosion, and absorption, some of them having been liberally eaten into by the invading magma, and others thoroughly impregnated by it (see Pl. XVII, fig. 1). Large outcrop also of a rock consisting of an intimate mixture of older and younger norites. Farther north, a dolerite-dyke is seen cutting older and younger norites.

(v) Point on the south side of Whale River, York.—One exposure shows coarse dolerite invading and shattering normal norite; the junction is crossed by a later fine-grained dolerite-dyke.

(vi) John Obey Point.—A large intrusion of coarse norite: its junction with the normal rock on the north side is almost 100 yards wide, and shows a great intermingling of the two types. Innumerable veins, tongues, and masses of the coarse pierce the normal rock, which shows signs of a very high temperature and much absorption.

(vii) Samuel Island.—Numerous intrusions of younger norite along the foreshore. The margins exhibit banding and streakiness due to the intermixture of the two rocks.

(3) The Beerbachite.

In the northern half of the Colony, and principally in the Freetown district, occur intrusions of a fine-grained, granular rock,[1] dark grey when fresh and weathering to pale grey; it sometimes shows a faint parallel structure in thin section. It consists essentially of labradorite, with subordinate hypersthene and magnetite, and its specific gravity is 3·08. A partial analysis of a

[1] The 'norite-aplite' of Prof. S. J. Shand, Geol. Mag. 1918, pp. 22, 23; he classifies the rock as melanocratic norite (m_6—micronorite).

single specimen of the rock shows:—Silica 47·96 per cent., alumina 12·78, iron-oxides 11·19, and magnesia 16·58. This rock is a variety of beerbachite (Chelius), defined by H. Rosenbusch[1] as a fine-grained to compact granular rock, composed of labradorite (sometimes bytownite) and diallage, with variable amounts of hypersthene and magnetite; he states also that olivine-bearing varieties occur. Similar rocks are figured by Dr. J. S. Flett in the Lizard Memoir, and by Rosenbusch in his 'Elemente der Gesteinslehre.'[2] The rock described by the former, referred to again below, occurs in the form of dykes in the Lizard gabbro, and consists mainly of granular labradorite and augite.[3] Rosenbusch states[4] that beerbachites occur in the gabbros of Rum and Kilhoan (Ardnamurchan) and in that near Harzburg. Similar rocks occur also among the Skye gabbros, and are described as 'granulitic gabbros' or 'pyroxene-granulites.'[5]

The 'fine-grained granulitic gabbro' of the Duluth laccolite[6] so closely resembles the Sierra-Leone beerbachite that microphotographs of the two rocks can scarcely be distinguished. This granulitic gabbro, like the beerbachite now considered, is both darker and denser than the rock of the main intrusion.

J. W. Judd[7] has explained the texture of certain Tertiary granulitic gabbros as due to crystallization of a moving magma in which the grains as they were formed were rolled around and prevented from interlocking freely. The Sierra-Leone beerbachite evidently crystallized under somewhat similar conditions, because fragments of norite caught up in it were softened, disintegrated, and drawn out into streaks (see below, p. 315). On the other hand, a few coarsely-crystallized and fresh-looking patches, free from obvious signs of contact-metamorphism, probably represent portions of the magma which crystallized under static conditions.[8]

With further reference to the Lizard beerbachite, it is evident, from some interesting notes recently published by Prof. T. G. Bonney,[9] that this rock is very closely paralleled in occurrence and field-characters by the Sierra-Leone beerbachite. For instance, the Sierra-Leone rock also is frequently 'brown-speckled' on a weathered surface, and it occurs in small masses rather than as veins; it invades a gabbro-mass made up of separate intrusions of different textures, and is followed by a series of dolerite-dykes. But the closest parallel of all appears in the way in which the Sierra-Leone

[1] 'Elemente der Gesteinslehre' 3rd ed. (1910) p. 282.
[2] *Ibid.* fig. 6, p. 57.
[3] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 110 & pl. ix, fig. 5.
[4] 'Elemente der Gesteinslehre' 3rd ed. (1910) p. 283.
[5] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 115.
[6] M. L. Nebel, Econ. Geol. vol. xiv (1919) p. 379; also pl. xiv, fig. *d*.
[7] 'On the Gabbros, Dolerites, & Basalts of Tertiary Age in Scotland & Ireland' Q. J. G. S. vol. xlii (1886) p. 49.
[8] Compare the coarse-grained rock cutting the Duluth granulitic gabbro: see M. L. Nebel, *op. supra cit.* p. 381.
[9] 'Beerbachite at the Lizard' Geol. Mag. 1920, p. 339.

rock has, like that of the Lizard, incorporated fragments of the gabbro, softened and disintegrated them, and isolated their felspars into clusters and strings.

The exposures of the Sierra-Leone beerbachite are generally small, and often are only a few yards across. Nevertheless, those which occur on Wilberforce Spur, on Mount Aureol, and in the Congo Valley respectively, corresponding to as many separate intrusions, are much more extensive than the others, and probably range up to 150 yards in length. The first of these intrusions shows interesting contact-phenomena with the younger norites, while the second displays a wide zone of hybrid rock produced by interaction with the older norite.

The Wilberforce Spur intrusion crosses an ill-defined junction between the older and younger norites over part of its outcrop, but elsewhere it is confined to the younger norite. It affects the two invaded rocks in the same manner. The beerbachite-magma possessed a great power of corroding and even of assimilating the norite, and all stages in the process from a fairly sharp junction to complete permeation can be observed in the field. The beerbachite contains blocks and fragments of norite, some of them having clean outlines and traversed by veins, others with deeply-indented margins showing where they have been attacked; yet others, more completely altered, are merely 'ghosts,' in that (although their original outlines are still faintly defined) they actually consist of mixtures in which corroded crystals and small fragments of the original rock are enclosed in a mass of beerbachite. This alteration has proceeded on a much larger scale at Mount Aureol, where the intermixture of normal norite and beerbachite has produced a hybrid rock. This hybrid rock is exposed along the sides of the unfinished motor-road, which runs around the flank of the hill from a kind of barrack-square to the G.O.C.'s house on the top. The road passes in turn over normal norite, beerbachite, the hybrid rock, and, finally, near the G.O.C.'s house, normal norite again. The hybrid rock forms an ill-defined zone about 150 yards wide, and, although it is better developed on Mount Aureol than in any other known locality, the actual exposures are poor, and consist chiefly of small masses and residual boulders more or less enveloped in laterite. The hybrid rock is darker than either of the parent rocks; it usually contains numerous small spots and streaks, most of which are dirty brown to black, while many others are pale grey. The rock is tough, and possesses an irregular fracture.

The invading magma continued to flow after the enclosed norite-fragments had become plastic and more or less disintegrated; these fragments were consequently so drawn out into streaks that many of their crystals became isolated, or were broken down into 'augen.' Specimens collected show strings of augite-fragments and of white lenticles that represent felspars, and also the attenuated remnants of sponge-like crystals of magnetite (see Pl. XVII, fig. 2).

(4) The Norite-Aplite.

Veins of norite-aplite may not infrequently be seen in the norite: generally they do not exceed 1/8 inch in thickness, but in one locality, near York, they are much thicker, and one of them for a short distance attains a thickness of as much as 9 inches. The veins tend to become more acid with diminishing width, and so at their terminations they may consist almost wholly of quartz and micropegmatite. The thin veins, however, which are white, are very persistent, and can be traced for 20 yards or more across an outcrop of norite without altering appreciably in thickness. The thicker veins consist of a medium-grained rock having a pale greenish tinge, and made up chiefly of acid soda-lime felspar, orthoclase, quartz, and micropegmatite, with small quantities of pyroxene (both rhombic and monoclinic), hornblende, biotite, and apatite (see Petrographical Notes, p. 322).

The norite-aplite-veins are the youngest intrusions of the norite-complex, apart from the dolerite-dykes which are seen to traverse the veins in several localities; evidence for this may be seen in the Congo Valley, below Hill Cot, where thin veins of norite-aplite traverse a large intrusion of beerbachite. It is interesting to note, moreover, that the veins are frequently associated with the master-joints of the norite, often running parallel with, or along them, for considerable distances. The affinity of the norite-aplite to the preceding intrusions is indicated, however, in the similarity of these rocks as regards certain chemical and mineralogical characters, such as the presence of rhombic pyroxenes. Nevertheless, there is reason to believe (see p. 317) that the aplite is related to the dolerite as much as, or even more than, to the norite; also that the aplite bears a magmatic relation to the dolerite similar to that which the segregation-veins and norite-pegmatite do to the norite. If this be so, the norite and dolerite of the complex show an interesting parallel with the olivine-dolerites and quartz-dolerites of the Edinburgh district, in that these Scottish dolerites are each cut by segregation-veins related in composition to the parent mass.[1] Moreover, this view of the magmatic relations of the aplite is supported by the fact that typical gabbro-aplites, such as those occurring in the gabbros of Rum and Skye (see below), are free from quartz and micropegmatite.

The specific gravity of a specimen of norite-aplite taken from one of the thicker veins was found to be 2·72.

The aplite-veins generally effected a slight alteration of the wall-rocks, shown chiefly in silicification of the felspars and uralitization of the pyroxenes; this alteration appears in the hand-specimen as a whitish zone, nearly an inch wide, enclosing the finer veins. The margins of the veins are, nevertheless, sharply defined.

The thin aplite-veins of St. David's[2] differ considerably from

[1] 'The Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. 1910, pp. 289 & 307.

[2] J. V. Elsden, 'The St. David's Head Rock Series' Q. J. G. S. vol. lxiv (1908) p. 283.

those of Sierra Leone; for instance, they apparently cut only the more acid members of the series, and they are free from ferromagnesian constituents and micropegmatite. Moreover, they are considered to be of contemporaneous origin, whereas those of Sierra Leone are distinctly younger than the enclosing rock.

(5) The Dolerites.

The injection of a number of dolerite-dykes, seen in different localities to cut all the earlier intrusions, marked the last phase in the history of the complex. It is quite possible, however, since in the field the dolerite is distinguished with difficulty from certain of the later intrusions of norite, that a few of the dolerite-dykes were intruded considerably in advance of the main series.[1] The dykes not infrequently made their way along the same channels as the preceding aplite-veins; this procedure is indicated chiefly by the presence of patches of aplite still adhering to their original walls, and also by a whitish alteration-product of the walls due to a contact-effect characteristic of the aplite. Sometimes, however, the invading magma forced its way between an aplite-vein and its wall-rocks, resulting in the inclusion of long irregular lenticles of aplite parallel to the margins of the dolerite. An excellent example of this may be seen on the foreshore a short distance north of York; here, included in a dolerite-dyke about a foot wide, is a highly-corroded aplite-xenolith 4 feet long and about 6 inches in maximum width. Several smaller xenoliths accompany the bigger one.

The dykes show interesting affinities to both the norite and the norite-aplite. To the norite they are related by the presence of a rhombic pyroxene which accompanies the augite: in the smaller dykes and in the marginal phases of the larger dykes, the rhombic pyroxene is enstatite; but in the central portion of the larger dykes the enstatite is replaced by a form approaching the common hypersthene of the norite [C. 121].[2] In this connexion it may be pointed out that, with regard to certain basic rocks near St. David's, Dr. J. V. Elsden[3] considered the thin intrusions of enstatite-diabase to differ from neighbouring quartz-norites only in ophitic tendency. To the norite-aplite, on the other hand, the dolerite-dykes are related by the presence of interstitial orthoclase and acid plagioclase, often considerable in amount, together with enstatite, some biotite, and innumerable needles of apatite. Thus it would appear, particularly in view of the field relations, that the aplite-veins were the forerunners of the dolerite, rather than the successors of the norite.

[1] In one locality, near York, coarse dolerite is traversed by a dolerite-dyke possessing chilled margins.

[2] Throughout this paper the numbers in square brackets refer to thin sections of the 'Colony' rocks.

[3] 'On the Igneous Rocks occurring between St. David's Head & Strumble Head (Pembrokeshire)' Q. J. G. S. vol. lxi (1905) p. 591.

The dykes consist essentially of a more or less ophitic enstatite-dolerite, free from olivine and containing variable amounts of interstitial acid felspar (see Petrographical Notes, p. 324). The specific gravity of the rock is 3·08. Thus we have in the one area two series of basic intrusions, not differing greatly in age, the one (norite) characterized by the presence of olivine, and the other (dolerite) free from this mineral; this association recalls the well-known occurrence of both olivine- and quartz-dolerites among the Carboniferous intrusives of the Edinburgh district.[1]

The Sierra-Leone dolerite-dykes are exposed in considerable numbers along the foreshore on the south-western coast of the Colony; elsewhere, with the exception of one cutting across the lower part of the Charlotte Falls, they have not been observed, probably because the rocks that may contain them are poorly exposed. Most of them are of an irregularly branching habit, and single examples can rarely be traced far enough to give a mean strike. The average direction of a number of which the strike could be measured, was north 35° west. They vary in width from a few inches to nearly 20 feet; the narrower are fine-grained and compact with sharp chilled margins, whereas the wider are coarse and are sometimes porphyritic with augite and felspar. Near York, one of the coarser dykes contains numerous skeletal crystals of ilmenite, and it cuts a series of fine aplitic veins in the norite. Others are vesicular, either along their margins or centrally.

In addition to the dykes several masses of coarse dolerite occur in the norite; their boundaries are ill-defined, and their exact relation to the enclosing rocks difficult to determine.

The Sierra-Leone dolerites closely resemble certain quartz-dolerites which occur elsewhere. For instance, they are similar in several respects, particularly the strong zoning of the felspars,[2] to the Carboniferous quartz-dolerites of Scotland; but the pale rhombic pyroxene of these Scottish rocks is identified as a form of hypersthene. Despite the obvious resemblances, however, it should be noted that both quartz and micropegmatite are apparently absent from the Sierra-Leone dolerite, the interstitial matter of which consists only of orthoclase and highly-acid plagioclase. Like that of the Scottish quartz-dolerites and of most of the rocks mentioned below, this interstitial matter is riddled with long needles of apatite. Other similar rocks are the Ratho intrusion near Edinburgh,[3] the Whin Sill,[4] certain intrusions of the Kilsyth-Croy district (Dumbartonshire),[5] and those of Arran.[6]

[1] 'The Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. 1910, p. 289.

[2] *Ibid.* p. 305 & pl. ix, fig. 3.

[3] J. J. H. Teall, 'British Petrography' 1888, p. 190; & J. S. Flett, 'The Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. 1910, p. 306.

[4] J. J. H. Teall, Q. J. G. S. vol. xl (1884) p. 640.

[5] G. W. Tyrrell, Geol. Mag. 1909, p. 305.

[6] A. Harker, 'The Geology of North Arran, &c.' Mem. Geol. Surv. 1903, p. 111.

The mineralogical differences between the various members of the norite-complex may be summarized in tabular form as follows:—

	Plagioclase.	Rhombic Pyroxene.	Monoclinic Pyroxene.	Olivine.	Iron-Ores.	Biotite.	Hornblende.	Apatite.	Orthoclase.	Quartz.
Norite	▬	▬	▬	▬	▬	–		–		
Beerbachite..	▬	▬	━		▬			–		
Norite-Aplite	▬	—	—			—	—	—	━	━
Dolerite	▬	━	▬		━	—		━	━	

The relative frequency of occurrence of the minerals is represented by the magnitude of the dashes as follows, in descending order :— ▬ ━ — –

(6) Differentiation and Assimilation.

Several stages of differentiation may be distinguished in the Sierra-Leone rocks:—

(i) Deep-seated differentiation.—The source from which the complex was derived underwent differentiation into a series of cognate sub-magmas which, on the whole, became intruded in the usual order of decreasing basicity: norites proper, rich in olivine, were the first to arrive, and they were followed in turn by norite-pegmatite and beerbachite. Then came the aplite-veins, very small in total volume, and finally a series of enstatite-dolerite dykes free from olivine and often rich in interstitial acid felspars.

(ii) Differentiation during intrusion.—The cooling of the normal norite-magma on intrusion led to a partial separation of the felspathic and ferromagnesian constituents in the liquid state. This heterogeneous product was drawn out, as intrusion proceeded, into bands which were fixed later by crystallization. The resultant banding was sometimes accentuated by small quantities of the coarse norite-magma, which were caught up by the normal norite-magma and interbanded with it.

(iii) Differentiation in place.—This phase led to the segregation of magnetite from the remaining constituents, and produced the streaks of this mineral within and parallel to the margins of certain bands. Locally, the ferromagnesian constituents separated out in a similar manner, and formed small patches.

Assimilation.—An interesting feature of the Sierra-Leone complex is the great amount of absorption suffered by earlier rocks when invaded by later intrusions; the absorption of older norite by younger norite and of both older and younger norites by beerbachite are examples of these reactions. With regard to the norites themselves, this absorption is the more remarkable, in that the composition of the later rocks differed but slightly from that of the earlier rocks. Cases have been described in which a basic magma has been modified by the absorption of an acid rock,[1] or, more frequently, in which an acid magma has been modified by the absorption of a basic rock: as, for example, the Lizard Kennack gneiss[2] and the 'marscoite' of Skye[3]; but a basic magma has rarely been known to absorb basic rocks. Even where a basic magma has invaded an ultrabasic rock, as where the basic rocks of Rum[4] and Skye[5] break through and invade the ultrabasic rocks, the older rock has simply been broken up and finally involved with the newer rock to form an intrusion-breccia, while little or no corrosion has taken place. As may be expected, however, a magma has sometimes been known to absorb a rock of similar composition locally, as where the Skye gabbro has 'to a limited extent actually fused and incorporated' basaltic lavas. As a general rule, however, it is not to be expected that a magma should absorb readily a rock of similar composition, since there is little scope for mutual chemical reaction, and the invading magma would carry little, if any, excess of heat.[6]

The unusual extent to which absorption has proceeded in the case of the Sierra-Leone norites is ascribed chiefly to the great depth at which the action took place; this would result in a high initial temperature for the invaded rocks, and would also prevent the heat of the intrusions from escaping, thereby allowing a great length of time during which the reactions could proceed. Moreover, there is considerable evidence to show that many of the numerous later intrusions of norite are all parts of one or more large intrusions, of which only the irregular upper portions are at present visible.

(7) Weathering and Lateritization of the Norite.

Where the products of weathering are unable to accumulate, the highly-resistant magnetite stands out in sharp relief on the surface of the norite, which in the majority of cases consists largely of felspar, since the pyroxenes disintegrate most easily. Along the foreshore the norites rich in iron weather to a smooth surface

[1] As, for example, Purcell Sills; see R. A. Daly, Mem. 38, Geol. Surv. Canada, 1912, pt. i, p. 248.

[2] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 132.

[3] 'The Tertiary Igneous Rocks of Skye' *Ibid.* 1904, p. 183.

[4] *Ibid.* p. 69.

[5] *Ibid.* p. 64.

[6] A. Harker, 'The Natural History of Igneous Rocks' 1909, p. 357.

covered with a thin ferruginous skin, which possesses a dull metallic lustre, is dark brown to black, and very hard.

A more detailed account of the lateritization of the norite has been given elsewhere.[1]

At Mount Aureol the lateritization of well-jointed norite has given rise to a curious effect, in the form of a slightly-raised and regular lattice-work on what is now the floor of an old barrack-square. Originally the norite at this place was strongly affected by two series of joints which ran at right angles; there was also a third series of joints, running obliquely to the others, and less well developed. The joints at right angles formed a large number of small rectangles with sides measuring as much as 12 inches in length. Lateritization first proceeded along the joints, and then it attacked the intervening spaces; the first-formed laterite was, however, more resistant than the second, and this relative hardness ultimately led to the formation of a raised rectangular pattern on the floor of the square.

(8 *a*) Iron-Ores in the Norite.

The iron-ores that occur in the norite are magnetite, ilmenite, and intermediate forms: octahedra of magnetite have been collected, as also skeletal crystals of ilmenite; but in general the ores are not distinguishable in the field, and the term magnetite will be used here to include them all. All forms of the norite include magnetite as larger or smaller disseminated grains: it is developed also as spongy growths, or as dense shapeless masses measuring up to 3 inches in length, and even as streaks and seams several inches thick, formed as the result of segregation in the banded norite. Locally, the norite is very rich in such ores; but the occurrences are not individually large enough for commercial exploitation.

A considerable quantity of iron-ore crops out along the foreshore west of Aberdeen Creek. The norite at this place is highly ferruginous, and contains numerous seams of magnetite intergrown with variable amounts of felspar; nevertheless, almost all the iron exposed is in the form of red oxide (hæmatite) due to the alteration of the magnetite *in situ*, and to concentration of the iron with progressive lateritization of the norite. The foreshore south of York over a distance of some hundreds of yards consists of coarse norite richly impregnated with magnetite as small segregations and as narrow seams, and north of John Obey is a small exposure of coarse norite showing magnetite-crystals (measuring as much as 3 inches in length) intergrown with pyroxenes.

The coastal plain which extends intermittently all around the Colony consists almost entirely of detritus washed down from the mountains, and since the iron-ore (when weathered out from the parent rock) is carried downwards in the form of grains and

[1] See F. Dixey, 'Notes on Lateritization in Sierra Leone' Geol. Mag. 1920, p. 211; also W. M. Davis, 'Physiographic Relations of Laterite' Geol. Mag. 1920, p. 429.

lumps of magnetite, it follows that the detrital accumulations should contain a large quantity of iron, a quantity which decreases as the distance from the mountains increases. Investigation confirms this, and in one locality on the north side a considerable deposit of iron-ore has been found along the inner margin of the plain. Most of this iron occurs now in the form of strings and small masses of hæmatite running through the laterite, which is itself in places sufficiently rich to rank as an ore. Elsewhere in the beds constituting the plain there is always quite enough iron-oxide to form a thick hard crust of laterite.

(8 *b*) Other Economic Minerals.

Economic minerals other than iron-ores seem to be developed only to a very slight extent in the norite, and this is probably due to the absence of basic and marginal phases to the intrusion. An analysis published in 1910 indicated 3·28 per cent. of chromic oxide in a specimen of iron-ore taken from 'Bathurst Mountain.'[1] The present investigation, however, has not furnished any indication of this amount, either in the field or in thin section, and recent analyses carried out in connexion with the work do not show in any one case more than 0·1 per cent. of the oxide; in most cases it is altogether absent. Nickel-oxide also has been shown by one of these analyses to be present up to 0·1 per cent. Sulphides are represented only by grains of pyrites which are seen but rarely in thin sections of the rock. A series of concentrates of stream-gravels has yielded nothing of interest, other than small quantities of rutile.[2] Bauxite containing over 51 per cent. of alumina occurs in considerable quantity, as a decomposition-product of the norite.[3]

III. Petrographical Notes.

(1) The Norite-Aplite.

An examination of a series of thin sections has shown that the veins of norite-aplite become increasingly acid in composition towards their extremities.

A specimen from a vein of medium texture, 9 inches wide, was found to consist chiefly of acid plagioclase, with much micropegmatite and a little quartz and orthoclase. In addition, it contained small amounts of enstatite, brown hornblende, brown biotite, magnetite, and apatite (the last-named as clouds of minute parallel needles in the felspar, and as fairly numerous grains and prisms). The plagioclase, from consideration of the refractive index and

[1] 'Iron-Ore Resources of the World' Stockholm, vol. ii (1910) p. 1029.

[2] Note the occurrence of rutile in certain anorthosites of Quebec: J. P. Iddings, 'Igneous Rocks' vol. ii (1913) p. 358.

[3] For an analysis of bauxite, see F. Dixey, Rep. Geol. Surv. Sierra Leone, 1921, p. 18.

extinction-angles, is determined mainly as oligoclase; its twin-lamellæ are exceedingly fine. The felspar of the micropegmatite is frequently seen to possess twin-lamellæ. The enstatite is pale green, and generally non-pleochroic; it occurs as skeleton-crystals and also as rods and grains, all associated with numerous grains of iron-ore. Some crystals, densely crowded with minute rod-like inclusions, exhibit a slight greenish pleochroism. Certain other vague pyroxenic patches occur in the slide, crowded with grains of iron-ore. These, like most of the ferromagnesian minerals in the gabbro-aplites of Skye,[1] are probably the remains of pyroxenes caught up by the norite-aplite during intrusion. A variety of medium-grained norite-aplite is seen as an inclusion in a dolerite-dyke, which has forced its way along the same course as an earlier aplite-vein. This variety is more acid; it consists chiefly of granular quartz and orthoclase; an acid plagioclase occurs as well, and generally takes the form of relatively large crystals. The following minerals are also present:—pale-green pyroxene, brown and green hornblende, brown biotite, magnetite, and apatite, all showing much the same characters as in the first variety. The fine extremities of the veins are rich in quartz and micropegmatite, but the other minerals are generally represented in them also.

(2) The Dolerites.

The dolerites are not often wholly of the ophitic type; frequently they show both ophitic and intersertal structure in the same slide, due to the variable habit of the pyroxenes.

The ophitic structure is developed when the felspars penetrate irregular plates of pale-brown augite; these augites, commonly about 1/8 inch in diameter, are scattered through the rock in great numbers, and, owing to the numerous grains of iron-ore and small flakes of brown biotite associated with them, they impart to the slice a markedly patchy appearance. They are sometimes almost opaque with inclusions. In the remaining parts of the slice, the pyroxene is chiefly a colourless to pale-green enstatite, which is slightly pleochroic and of granular habit; grains of this mineral are often involved in the areas of clear felspar interstitial to the common felspars of the rock.

The finer varieties of dolerite, occurring near chilled margins and in thin dykes, consist of minute laths of felspar, with interstitial granules of augite and iron-ore. The coarser types, developed in the large dykes, sometimes contain phenocrysts of felspar possessing fine twin-striation and occasional signs of corrosion [C 125]. In one other variety [C 121], from the middle of a dyke 18 feet wide, the pyroxenes were developed in the form of coarse grains showing a tendency to idiomorphism; a number of these grains belonged to the rhombic system, and possessed a pale-brownish pleochroism. This rock is of especial interest, as showing an intermediate stage between dolerite and norite.

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 119.

The felspar of the ordinary dolerite is of two kinds: the one occurs as laths and is turbid, whereas the other is interstitial and almost water-clear. The laths have a narrow clear margin, which is optically continuous with parts of the adjacent interstitial felspar. Thus the felspar-laths are strongly zoned, and where the margin of the microscope-slide cuts across one of them, it is interesting to trace the variation in refractive index from the centre of the crystal to its outer limit. In this way it can be demonstrated, just as in the case of certain Scottish quartz-dolerites,[1] that the composition of the laths ranges from basic labradorite to acid oligoclase. The felspars making up the larger areas of clear interstitial material range from oligoclase to orthoclase in composition, and they are riddled by numerous needles of apatite. Some of these felspars, determined as orthoclase, have short rectangular outlines; while others possess a curious streaky appearance suggestive of anorthoclase.

These clear areas, and the minerals that compose them, closely resemble the interstitial portions of the Whin Sill and of certain Scottish and Pembrokeshire quartz-dolerites.

The iron-ores of the dolerite are generally abundant; they occur as microliths, grains, and irregular masses, the last-mentioned sometimes assuming curious wheel-like and other forms similar to those described by Mr. G. W. Tyrrell from the Kilsyth-Croy intrusions.[2]

(3) The Minerals of the Complex.

Quartz.—In the aplite-veins, particularly at their fine extremities, quartz occurs in fair amount, both in granular form and in graphic intergrowth with felspar; the felspar of the intergrowth is generally orthoclase, but in some cases it is an acid plagioclase. In the norite, however, quartz does not occur as a normal product of crystallization; this is only to be expected, since olivine is so commonly developed. Nevertheless, it is interesting to note that there was probably a small excess of silica at the time when the felspars were crystallizing; later, as the felspars attained a lower temperature, this excess was precipitated in the form of strings and small patches of granular quartz.

Felspars.—The only felspar of the normal norite is an acid labradorite the composition of which is near Ab_3An_4, as determined by extinction-angles and refractive index. This felspar is fresh and clear, grey in colour, and free from zoning. It generally forms pinacoidal tables with Carlsbad and albite twinning; pericline twinning occurs also. The grey colour of the felspars in the hand-specimen is due to the presence of innumerable minute opaque

[1] 'The Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. Scot. 1910, p. 305.

[2] 'Geology & Petrology of the Intrusions of the Kilsyth-Croy District (Dumbartonshire)' Geol. Mag. 1909, p. 308.

black inclusions; these inclusions, which apparently consist of iron-ore, may occur in parallel bands along certain twin-lamellæ, or may be scattered irregularly throughout the crystal. They generally lie parallel to two or more crystallographic planes in the felspar. They are much more numerous in the felspar of the younger norites; this felspar, approaching bytownite in composition, is more basic than that of the normal norite. The felspar of the beerbachite, on the other hand, is slightly more acid than that of the normal norite. The plagioclase occurring in the aplite-veins belongs to the acid end of the soda-lime series; it exhibits minute twin-striation, and its variable composition is indicated by strong zoning. Finally, the plagioclase of the dolerite ranges in composition from basic labradorite to acid oligoclase; the basic portions of a crystal form a turbid central area, whereas the acid parts make up a clear relatively narrow external zone. Porphyritic plagioclases occur locally in some of the finer-grained phases of the norite; the phenocrysts do not differ appreciably from the groundmass felspars in composition, and moreover, like the latter, they contain occasional strings and clots of granular quartz.[1]

Orthoclase occurs as a constituent of the aplite-veins, and it is present also in the interstitial material of the dolerite.

Locally, the more basic felspars show small quantities of a pale-brown alteration-product, which is developed in fibrous form transversely to cracks; sometimes it appears as minute rhombs [C 48]. It is of low refractive index and feeble birefringence.

The felspar of the norite enters into an interesting series of intergrowths with magnetite, augite, and olivine (see below, p. 329).

Pyroxenes.—Next to the felspars the pyroxenes are the most abundant minerals in the norite. They consist essentially of augite and hypersthene; but there occur also small quantities of a pale augite, and of a colourless rhombic pyroxene. Enstatite occurs in both the aplite and the dolerite.

The augite of the norite is chiefly a smoky-brown diallage; schillerization, as lines of minute grains and rods of iron-ore, is sometimes strongly developed. Not infrequently the augite faintly simulates the pleochroism and polarization-colours of the hypersthene; a similar feature has been noted in the augite of the Kilsyth-Croy intrusions by Mr. G. W. Tyrrell, who attributes it to the presence of the hypersthene-molecule in the augite.[2] A colourless to pale-green augite, probably diopside, occurs in the aplite-veins.

The hypersthene of the norite is associated with the augite in variable proportions; generally, however, it is subordinate to the augite. It is less common in the older than in the younger norite.

[1] Quartz occurs similarly in the Charnockite Series: see A. Harker, 'The Natural History of Igneous Rocks' 1909, p. 261.

[2] 'Geology & Petrology of the Intrusions of the Kilsyth-Croy District (Dumbartonshire)' Geol. Mag. 1909, p. 306.

It occurs in various tints of brown: the pleochroism, which is generally strong, has been observed as follows:—

X, light-red to brownish red; Y, reddish yellow; Z, pale green.

Bastite is of rare occurrence only; sometimes, however, the hypersthene contains yellow-green fibrous veins of a mineral which resembles delessite: this mineral has been noted in the hypersthene of the Charnockite Series[1] and in the 'pyroxene-leptynite' (Lacroix) of Ceylon. Hypersthene is practically the only pyroxene of the beerbachite, in which it is more or less granular, with a tendency to idiomorphism. In the coarser rocks, on the other hand, it sometimes forms large irregular plates enclosing all the other minerals, after the manner of the big ragged augites in the eucrites of Rum.[2] Schillerization is developed much as in the diallage, except that the inclusions are larger and consist of a brown birefringent mineral. The hypersthene sometimes shows a fine multiple twinning: this is probably secondary, and analogous to that sometimes produced in felspars by local pressure. Rarely, two sets of twinning are seen, crossing at right angles.

The enstatite of the aplite-veins is often idiomorphic, and not infrequently it takes the form of bladed skeleton-crystals; in the dolerite it generally occurs as anhedral grains. It is colourless to pale green, optically positive, and the pleochroism, when visible, is X and Y yellowish or yellow-green and Z green; this pleochroism is rarely detected, except in those forms that are crowded with minute rod-like inclusions.

The order of crystallization of the various pyroxenes is distinctly variable. The pale augite usually appears as rounded patches in the diallage; small and fairly idiomorphic hypersthenes are sometimes enclosed in augite; but, on the other hand, plates of hypersthene may enclose augite-crystals.[3] At other times, the monoclinic and rhombic pyroxenes are intergrown; they then show the customary interpositions, and occasionally have a common crystallographic orientation. Several examples were seen, similar to those observed by Sir Jethro Teall in the dolerite of the Whin Sill,[4] and by Dr. J. V. Elsden in the norite of St. David's.[5] The latter observer has already shown (*op. cit.* p. 286) that

'the simultaneous separation of these minerals, as shown by intergrowths and compound twins, might represent the eutectic composition,'

in accordance with Prof. J. H. L. Vogt's view that in certain cases, the sequence of these minerals should be dependent upon the

[1] Mem. Geol. Surv. India, vol. xxviii (1900) p. 141.

[2] 'The Geology of the Small Isles of Inverness' Mem. Geol. Surv. Scot. 1908, p. 100.

[3] Similar relations are noted in the norite occurring near Huntly: see W. R. Watt, 'The Geology of the Country around Huntly (Aberdeenshire)' Q.J.G.S. vol. lxx (1914) p. 266.

[4] *Ibid.* vol. xl (1884) p. 649.

[5] *Ibid.* vol. lxiv (1908) pl. xxxii.

relative proportions of lime and magnesia present in the magma.[1] Vogt has shown elsewhere[2] that, when magnesia is largely in excess of lime, the rhombic pyroxene would crystallize first; it would then be followed by intergrowths of mix-crystals, and these latter by monoclinic pyroxene alone, in accordance with Roozeboom's Type IV of mix-crystals. There occurs also a lamellar intergrowth of hypersthene and augite similar to that of the pyroxenes in the St. David's, Whin Sill, and Duluth rocks; it ranges from strong banding down to lamellation so thin as to be scarcely perceptible microscopically. The finer phases of the lamellation and other intimately-related forms are probably due to deposition from solid solution. With reference to similar phenomena in the labradorite-norite of the Lofoten Islands (Norway), Prof. J. H. L. Vogt has stated that[3]

> 'By cooling down to ordinary temperature, ... the enstatite-hypersthene cannot carry so much $Ca(Mg, Fe)Si_2O_6$ in solid solution. Consequently some augite is separated out in perthitic lamellæ—corresponding with the perthitic lamellæ of albite or albite-oligoclase in perthitic striated microcline.'

The relations of the pyroxenes to the other principal minerals depend upon the relative proportions of the various minerals in the magma: when the pyroxenes are greatly in excess of the general eutectic, they are the first minerals to crystallize out. The eutectic minerals enter into an interesting series of intergrowths.

The pale augite occurring as rounded inclusions in the diallage is probably the monoclinic form of magnesia-pyroxene which Dr. Elsden has briefly discussed in his St. David's paper.[4]

Olivine.—This mineral is a common and often important constituent of both the older and the younger norites; some varieties of the norite consist almost entirely of olivine and felspar, while certain bands in the banded norite are very rich in coarse granular olivine. Olivine is absent from the normal beerbachite; but it is frequently present in this rock as xenocrysts derived from the norite. Olivine occurs principally in the norite, both as rounded blebs and as more or less idiomorphic crystals; sometimes it occurs as strings and clusters of contiguous crystals which, while presenting rounded outlines to other minerals, are themselves separated by clean crystal-faces. The crystallization of the olivine extended over a considerable period: where the mineral was relatively abundant it formed fairly idiomorphic crystals, but where it was in relatively small proportion, on the other hand, it developed as skeleton-crystals enclosing pyroxenes and laths of felspar. Locally, however, it formed a beautiful pœcilitic structure with the pyroxene; sometimes it entered into intergrowth with other minerals (see below).

1 'Die Silikatschmelzlösungen' pt. i (1903) p. 129 & pt. ii (1904) p. 109, Vidensk. Selsk. Skrifter, Christiania.

2 See J. V. Elsden, 'Principles of Chemical Geology' 1910, p. 166.

3 'On Labradorite-Norite with Porphyritic Labradorite-Crystals, &c.' Q. J. G. S. vol. lxv (1909) p. 101.

4 *Ibid.* vol. lxiv (1908) p. 288.

Normally, the olivine is remarkably fresh; apart from pale-green and yellow-green serpentine, the most important alteration-product is iddingsite. This mineral replaces the olivine first along cracks and then in the intervening spaces, until it forms large plates, varying in colour from deep brownish-red to yellow and green. It has strong double refraction, and is distinctly pleochroic, the colours ranging from red-brown to a yellowish tint, vibrating respectively parallel with, and at right angles to, the short axis of the polarizer. In the hand-specimen it has a good cleavage in one direction; the flakes, which can be separated with a knife, are somewhat brittle. It occurs most commonly in norite relatively rich in iron. The mineral bears a close resemblance to that described by Prof. W. S. Boulton from an intrusion of monchiquite in the Old Red Sandstone of Monmouthshire.[1] Well-marked reaction-rims are sometimes developed between the olivine and the felspar. The olivine frequently encloses beautiful dendritic magnetite.

Iron-Ores.—The chemical analyses of the norite indicate that the iron-ore contains a considerable percentage of titanium; examination of thin sections shows, however, that the amount of titanium varies in different specimens of the ore. Lateritic iron-ores derived from the norite have been found to contain as much as 20 per cent. of titanium dioxide. The ore apparently consists of a mechanical mixture of magnetite and ilmenite; for, when a sample is powdered, the two minerals can readily be separated by means of a magnet.[2] It is thus a titaniferous magnetite or 'titanomagnetite.' The magnetite (titanomagnetite) is present in all phases of the norite, but it is not always developed to the same extent. It occurs generally as irregular grains, some of which are rounded while others are more or less idiomorphic. It is often interstitial to other minerals of the rock, showing that its crystallization extended to a very late stage; on the other hand it not infrequently forms, as in the Skye gabbros, large plates in which all other minerals are embedded.[3] It enters into intimate intergrowth with other minerals (see below, p. 332), and even appears in some cases to be replacing them; similar relations have been noted in the Duluth gabbro, concerning which M. L. Nebel states that

> 'Magnetite is often later than augite and olivine, as well as plagioclase, as it is found surrounding and penetrating them in such a manner as to suggest corrosion of the older mineral and partial replacement by the magnetite (pl. xiii, c).' Econ. Geol. vol. xiv (1919) p. 372.

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[1] 'On a Monchiquite Intrusion in the Old Red Sandstone of Monmouthshire' Q. J. G. S. vol. lxvii (1911) p. 472.

[2] See J. H. L. Vogt, 'On Labradorite-Norite with Porphyritic Labradorite-Crystals, &c.' Q. J. G. S. vol. lxv (1909) p. 87; and also J. J. H. Teall, 'The Geology of the Glasgow District' Mem. Geol. Surv. Scot. 1911. p. 128.

[3] A. Geikie & J. J. H. Teall, 'On the Banded Structure of some Tertiary Gabbros in the Isle of Skye' Q. J. G. S. vol. l (1894) pl. xxviii.

The presence of ilmenite can occasionally be detected by characteristic cleavage and also by white patches and highly refracting borders of leucoxene; generally, however, the iron-ore is too fresh to show these decomposition-products. Narrow borders of pyroxene also occur, and scraps of biotite are often associated with the ore.

Although iron-ore occurs so persistently in the norite, and may even occur locally as numerous 'schlieren' up to 3 inches in thickness and as small masses several inches long, there are unfortunately no indications that the ore is anywhere sufficiently concentrated to be worth working for industrial purposes.

Hornblende.—Green and brown varieties of this mineral occur in the aplite-veins, frequently intergrown with biotite. It is absent from the norite, except where produced by contact-metamorphism (see below, p. 341).

Biotite.—This mineral normally occurs in the norite only as minute brown flakes associated with the iron-ores; it is fairly common in the aplite-veins and in the dolerite, and frequently arises in the norite as a result of contact-metamorphism.

Apatite.—As in the St. David's Head rocks,[1] this mineral occurs most commonly in the more acid members of the complex. It forms countless minute needles and numerous grains and prisms in the aplite-veins, and occurs abundantly also as small needles in the interstitial matter of the dolerites.

Zircon occurs sparingly in the complex in the form of minute prisms, and rutile has been found in concentrates of river-gravels.

(4) Intergrowths of the Common Minerals, and Crystallization of the Norite-Magma.

One of the most interesting features of the Sierra-Leone norite is the number of binary and ternary intergrowths occurring between the principal minerals.

Prof. J. H. L. Vogt,[2] in an investigation into the sequence and process of crystallization in gabbroidal rocks, noted in the labradorite-norite of the Lofoten Islands a ternary system which is closely paralleled in the Sierra-Leone norite. The labradorite-norite referred to was 'chemically and mineralogically on the boundary between labradorite-rock and norite'; it was porphyritic, with xenocrysts of labradorite. Vogt says (*op. cit.* pp. 91, 95):—

'We may distinguish between the following three stages of crystallization:—

[A.] (1) Plagioclase alone (phenocrysts);
(2) then plagioclase and magnetite contemporaneously;
(3) plagioclase, magnetite, and pyroxene-minerals, besides biotite, contemporaneously.

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[1] J. V. Elsden, 'The St. David's Head Rock Series' Q. J. G. S. vol. lxiv (1908) p. 289.
[2] *Ibid.* vol. lxv (1909) p. 81.

'If then we confine ourselves to the chief minerals, and if we provisionally look upon the two pyroxenic minerals as one unit, we find here the same three stages of crystallization as in the ordinary ternary systems consisting of independent components.'

In extension of this idea, the following series might also be expected to occur, since magnetite crystallized earlier than felspar, when the ratio of the magnetite-component to the felspar-component exceeded a certain quantity:—

B. (1) Magnetite.
(2) Magnetite and felspar (simultaneously).
(3) Magnetite, felspar, and pyroxene (simultaneously).

Both series A and B actually occur in the Sierra-Leone norite, even to the development of phenocrysts of labradorite in the less coarse varieties. Moreover, with a slightly increased proportion of pyroxene, the following modification of A is sometimes produced:—

C. (1) Felspar.
(2) Felspar and pyroxene.
(3) Felspar, pyroxene, and magnetite.

(The minerals of stage 2 and of stage 3, respectively, in this and the following systems crystallize simultaneously.)

There is also evidence in the formation of other binary and ternary intergrowths, graphic or otherwise, of the existence in the magma of a number of additional ternary systems, due to the inclusion of olivine as a fourth independent component; they include:—

D. (1) Felspar.
(2) Felspar and olivine.
(3) Felspar, olivine, and magnetite.

And E. (1) Pyroxene.
(2) Pyroxene and olivine.
(3) Pyroxene, olivine, and magnetite.

The development of the above ternary systems in the porite does not imply great variations in the composition of the magma as originally intruded, nor general variations in the resultant rock. There is evidence from the experiments of A. L. Day & E. S. Shepherd,[1] that magmas differing slightly in composition will, at different temperatures, give rise to a limited number of eutectics which differ considerably one from the other in composition and in the character of the minerals formed. The experiments referred to were made upon the lime-silica series of minerals, for which three eutectic points were found; but it seems very probable that the results would apply in some measure at least to the crystallization of more complex magmas such as occur in nature. Local variations in composition within the magma were probably set up in the course of crystallization and cooling, and they were doubtless complicated also by more or less superfusion and possibly viscosity.[2]

[1] Amer. Journ. Sci. ser. 4, vol. xxii (1906) pp. 265 *et seqq.*

[2] J. V. Elsden, 'Principles of Chemical Geology' 1910, p. 151.

F. D. photo.

Fig. 1.—The Sierra Leone Mountains, looking southwards from the Summit of Leicester Peak.

F. D. photo.

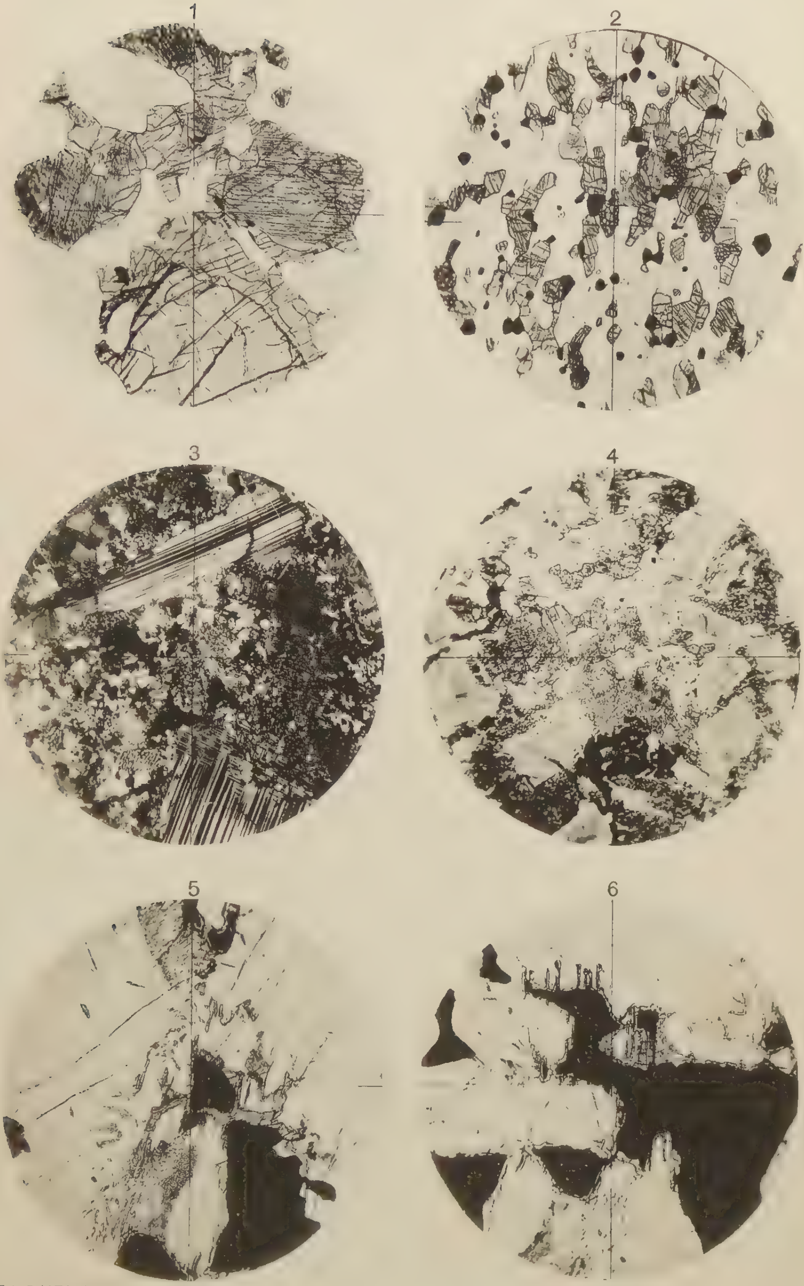
Fig. 2.—Contact of coarse Norite with older or normal Norite, Foreshore, near Godrich.

F. D. photo.

FIG. 1.—COARSE NORITE INVADING NORMAL NORITE. FORESHORE, NEAR YORK.

F. D. photo.

FIG. 2.—BEERBACHITE INVADING AND INCORPORATING NORMAL NORITE, WILBERFORCE SPUR.



F.D. PHOTOMICRO.

ROCKS FROM THE NORITE-COMPLEX OF SIERRA LEONE.

1

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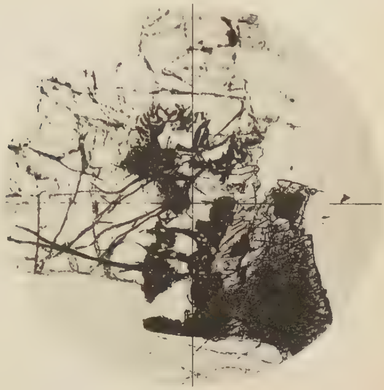

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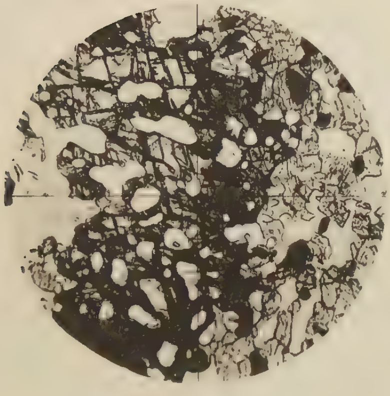

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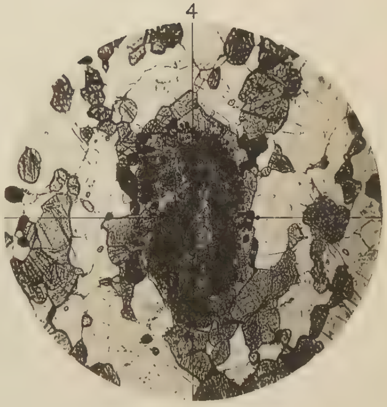

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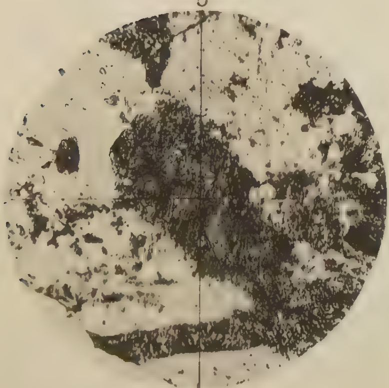

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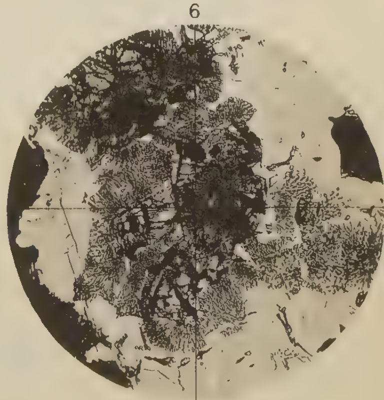


F.D. PHOTOMICRO.

ROCKS FROM THE NORITE-COMPLEX OF SIERRA LEONE.

In rare cases there is even seen a quaternary intergrowth composed of felspar, pyroxene, olivine, and magnetite. This intergrowth is of considerable interest, because it contains all the principal components of the rock, and is therefore practically the theoretical eutectic of the magma. An almost parallel case has been described by Dr. R. H. Rastall[1] from the Skiddaw Granite, in which a quaternary eutectic of four of the five principal components is sometimes developed.

The following is a brief description of the more interesting intergrowths of the Sierra-Leone norite and of corresponding intergrowths in other rocks:—

(i) Binary.—Plagioclase and augite form two types of graphic intergrowth in the norite. The first type is obviously primary, and occurs as narrow parallel rods of augite penetrating the felspar (see Pl. XVIII, figs. 5 & 6); a similar intergrowth has been noted in the Norwegian syenite-pegmatites,[2] in the coarser parts of the Rowley basalt,[3] and in the Duluth gabbro.[4] The second type is of slightly later age, and generally takes the form of a corona or reaction-rim partly enclosing biotite and olivine at their contact with plagioclase; it is developed only on the plagioclase side of the contact and spreads more or less fanwise into the felspars (see Pl. XIX, fig. 1). It is in general readily distinguished from the first type of intergrowth, both by its finer texture and by its relation to other minerals, particularly the felspars. The manner in which it is seen to spread through the felspars indicates that, although formed after the main period of crystallization of the rock, it was nevertheless connected in some way with the final stages of consolidation. That it is unlikely to be a secondary alteration-product is shown by the beautifully fresh condition of all the minerals of the rock. With regard to the production of a similar intergrowth in the Duluth gabbro, Nebel writes (*op. cit.* pp. 376–77 & pl. xiv, fig. *b*):—

'The evidence is not conclusive, however, as to whether the process was a phase of the last stages of crystallization of the magma, or whether it was a metamorphic process which took place after the rock was completely solidified. The fact that the gabbro shows many metamorphic features indicates that a metamorphic origin for the intergrowth is possible.'

Dr. J. J. Sederholm clearly favoured the theory that this intergrowth was of a secondary nature, and formed by metamorphic

1 'The Skiddaw Granite & its Metamorphism,' Q. J. G. S. vol. lxvi (1910) p. 120.

2 W. C. Brögger, 'Die Mineralien der Syenitpegmatitgänge der Südnorwegischen Augit- & Nephelinsyenite' Zeitschr. Krystallogr. vol. xvi (1890) pp. 149–52.

3 J. J. H. Teall, 'British Petrography' 1888, p. 212 & pl. xxiii, fig. 2.

4 M. L. Nebel, 'The Basal Phases of the Duluth Gabbro, near Gabamichigami Lake (Minnesota) & its Contact-Effects' Econ. Geol. vol. xiv (1919) p. 371 & pl. xiv, fig. *a*.

agencies later than the solidification of the rock.[1] In the Sierra-Leone norite, however, the intergrowth is frequently developed in places where it appears very unlikely that metamorphic agencies have had any influence. It is, nevertheless, true that intergrowths of felspar and augite are more abundant in the contact-altered norite than in the unaltered rock (see below, p. 338 & Pl. XIX, fig. 6), but this is due only to the increased opportunity of crystallization afforded by the great heat of the intrusions, whereby the two minerals, already present in eutectic proportions, could recrystallize in graphic intergrowth.

Plagioclase and olivine form relatively rare intergrowths that follow a crude graphic plan; the small blebs and short laths of olivine embedded in the felspar are in optical continuity with a neighbouring larger crystal of olivine. Similar occurrences have been noted and figured by W. S. Bayley[2] and M. L. Nebel.[3] These minerals occasionally enter also into simultaneous crystallization after the fashion of anorthite and olivine in the allivalites of Rum.[4]

Olivine and magnetite form a graphic intergrowth recalling the dendritic inclusions of magnetite in olivine. Intergrowths of these minerals have been described from certain rocks in Alnö.[5] In highly ferriferous parts of the norite, augite and magnetite may frequently be seen to bear similar interstitial relations to the remaining minerals; sometimes, in these circumstances, they enter into a graphic intergrowth consisting of rods of the two minerals lying parallel to the cleavage of the augite. Intergrowths of these two minerals have also been noted by Dr. A. Harker.[6] Moreover, hypersthene and magnetite enter into intergrowth in the form of plates of hypersthene enclosing graphic magnetite (see Pl. XIX, fig. 2). Intergrowths of the monoclinic and rhombic pyroxenes have been described above (see p. 326).

The following intergrowths also occur—(*a*) pyroxene and olivine[7]; (*b*) plagioclase and magnetite, in which rods and narrow tongues of magnetite penetrate the felspar[8]; and (*c*) in the aplite-veins, hornblende and biotite.

(ii) Ternary.—The most striking ternary intergrowth is that composed of parallel rods of felspar, pyroxene, and magnetite

[1] 'On Synantectic Minerals & Related Phenomena' Bull. Comm. Géol. Finlande, No. 48 (1916) pp. 9–46.

[2] 'The Basic Massive Rocks of the Lake Superior Region' Journ. Geol. vol. i (1893) p. 709.

[3] Econ. Geol. vol. xiv (1919) p. 372.

[4] 'The Geology of the Small Isles of Inverness' Mem. Geol. Surv. Scot. 1908, p. 88.

[5] R. Workman, 'Calcite as a Primary Constituent of Igneous Rocks' Geol. Mag. 1911, p. 193.

[6] 'The Natural History of Igneous Rocks' 1909, p. 271.

[7] Compare Vogt's researches on slags, 'Die Silikatschmelzlösungen' pt. i (1903) Vidensk. Selsk. Skrifter, Christiania.

[8] See also J. H. L. Vogt, 'On Labradorite-Norite with Porphyritic Labradorite-Crystals, &c.' Q. J. G. S. vol. lxv (1909) p. 81.

[C 68]. (See Pl. XVIII, fig. 6.) A second system, similar in many respects to one seen in the Duluth gabbro,[1] consists of pyroxene, olivine, and magnetite. In certain of these intergrowths minerals form angular and wedge-shaped masses, which irregularly interlock and enclose one another. Interlocking rhombic and monoclinic pyroxenes are occasionally associated with one other mineral in ternary intergrowth.

(iii) The principal minerals of the quaternary intergrowths are pyroxene, magnetite, and olivine; felspar enters in as the fourth constituent, intergrown graphically with one or more of the other minerals. These intergrowths are similar to the quaternary eutectics noted by Prof. Lacroix in certain pyroxene-gneisses.[2] Intergrowths of this order are sometimes formed also from the ternary intergrowths of the norite, through replacement of a simple pyroxene by intergrown rhombic and monoclinic pyroxenes.[3]

It is possible to express in a simple diagram the variable mineralogical composition of the norite and also the development of the ternary systems from magma of a given composition. It will be assumed in that part of the diagram which illustrates the sequence of crystallization in the ternary systems, that the crystallization proceeds without interruption or modification due to the formation of mix-crystals. This assumption is justified, with the minor exceptions of olivine and pyroxene taking up small amounts of magnetite and titanic oxide respectively, and of felspar absorbing small quantities of other minerals.[4] Substances held in solid solution in this manner tend to be precipitated on the cooling of the rock, and to assume the form of minute inclusions.

Suppose that the oxides SiO_2, $Fe_2O_3.FeO$, CaO, MgO, Na_2O, constituting the principal chemical components of the norite-magma, are placed at the angles of a pentagon (see fig. 2, p. 334). The area, as a whole, represents the general composition of the magma; the point SiO_2 represents the mineral quartz, and the points Al_2O_3 and $Fe_2O_3.FeO$, represent the minerals alumina and magnetite respectively; the areas CaO, Al_2O_3, SiO_2, and MgO, Fe_2O_3, SiO_2, felspar and olivine respectively; whereas the central part of the pentagon represents pyroxene. Now take a felspar, magnetite, and a pyroxene represented by the points A, B, C respectively; any point P within the area A B C will represent a combination of these three minerals, in proportions which are inversely as the distances of the point P from the points A, B, C. The composition of the magma representing the ternary eutectic of the felspar, magnetite, and pyroxene can then be found as follows:—Erect ordinates

[1] M. L. Nebel, Econ. Geol. vol. xiv (1919) p. 372.

[2] 'Contributions à l'Étude des Gneiss à Pyroxène & des Roches à Wernérite' Bull. Soc. Min. France, vol. xii (1889) p. 83.

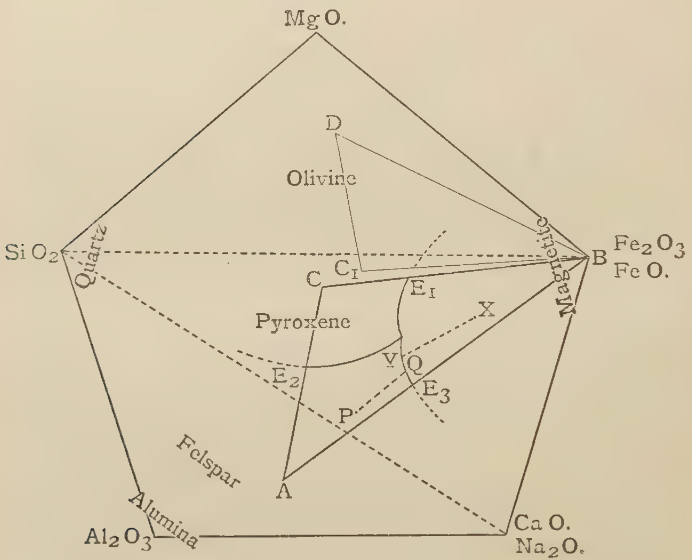
[3] See J. H. L. Vogt, 'On Labradorite-Norite with Porphyritic Labradorite-Crystals, &c.' Q. J. G. S. vol. lxv (1909) p. 81.

[4] See J. V. Elsden, 'Principles of Chemical Geology' 1910, p. 182.

Aa, Bb, Cc to represent temperatures, the points a, b, c being the freezing-points of the minerals A, B, C. Through a, b, and c will pass freezing-point surfaces for mixtures of A, B, and C, respectively, with the remaining two minerals.[1] Each pair of surfaces will intersect in a line formed by the eutectic points of the pair of minerals at different temperatures; the three lines representing the binary eutectics will meet in a point representing the ternary eutectic. Let E_1E, E_2E, and E_3E, represent the projection of the three lines on the area A B C; then the intersection (E) of these lines is the required point.

The order of events in the cooling and crystallization of a magma of composition P will be as follows: an indicating point vertically above P will descend as the magma cools, until it reaches

Fig. 2.



the freezing-point surface of the felspar (A) at a; then the felspar will begin to crystallize out, and the indicating point will travel along the surface on a line (the projection of which is PQ) directly away from a, until it meets the felspar-magnetite eutectic line at a point projected at Q. The magnetite will then crystallize in eutectic proportions with the felspar, and the indicating point will travel down the binary eutectic line of these two minerals until it reaches the ternary eutectic point, which is projected to E. Then

[1] See A. Harker, 'The Natural History of Igneous Rocks' 1909, fig. 60, p. 202. The notation which I have adopted is after that employed by him.

the three minerals (felspar, magnetite, and pyroxene) will proceed to crystallize together in eutectic proportions and at a stationary temperature.

Similarly, it will be seen that in the cooling of a magma of composition X, magnetite would crystallize out until the residue attained the composition Y, when felspar would crystallize with the magnetite; the remaining magma would finally attain the composition E, at which the ternary eutectic (magnetite, felspar, augite) would be formed, as before.

The ternary eutectic of a pyroxene C_1, an olivine D, and magnetite B, or of any other of the ternary systems described above, could also be expressed by this method.

(5) The Order of Crystallization.

It is obvious from the foregoing remarks that the order of crystallization in the norite-magma was far from being in accordance with the law, named after Rosenbusch, which commonly holds in the case of basic magmas. The principal departures from this law rest in the early crystallization of the labradorite, the prolonged and generally late crystallization of the iron-ores, the variable crystallization of the olivine and pyroxenes, and the late crystallization of the biotite. The order of crystallization followed the law, however, in the early precipitation of the apatite and zircon. Prof. J. H. L. Vogt's more simple law, demonstrated by his researches on slag,[1] that the order of crystallization is determined by the relative proportions of the several minerals present as compared with the eutectic proportions, seems to have been the leading principle. This is confirmed by the occasional development of a quaternary intergrowth which closely approaches the theoretical eutectic of the magma. With regard to similar conditions in the Skiddaw Granite (see above, p. 331) Dr. R. H. Rastall concludes:—

'It appears to follow that the order of crystallization was that which finally led to a eutectic composition which expressed itself as a graphic intergrowth of a varying number of components. The large and comparatively pure phenocrysts represent the excess of certain components over this eutectic ratio.' (Q. J. G. S. vol. lxvi, 1910, p. 121.)

Nevertheless, certain anomalies in the crystallization of the norite were possibly due to the influence of superfusion and viscosity; superfusion itself may cause not only reversals in the order of crystallization, but also may result in a marked sequence of separation in place of the simultaneous crystallization of the eutectic.[2] The early precipitation of the apatite and zircon

[1] 'Die Silikatschmelzlösungen' pt. i (1903) Vidensk. Selsk. Skrifter, Christiania.

[2] W. Meyerhoffer, 'Schmalzpunkte & Ausscheidungsfolge von Mineralien' Zeitschr. Krystallogr. vol. xxxvi (1902) pp. 593 *et seqq.*: see also J. V. Elsden, 'Principles of Chemical Geology' 1910, pp. 151 & 154.

is probably due to the immiscibility of these compounds with the common aluminous silicates.[1]

The actual order in which the minerals crystallized when not too strongly affected by eutectic proportions was as follows:—(1) apatite and zircon; (2) magnetite, olivine, and pyroxenes in small amount; (3) labradorite; (4) most of the olivine; (5) most of the pyroxenes; (6) most of the magnetite; (7) biotite; (8) micropegmatite and quartz. This order agrees closely with that of the Duluth gabbro.[2] The periods of crystallization, other than (1) and (8), were not always sharply defined, however, and a considerable amount of overlapping ensued: for instance, the magnetite, although occurring principally as in the above list, nevertheless kept up a certain amount of crystallization all through the periods, almost to the end. The magnetite of certain basalts in Franz Josef Land behaves in a similar way, as was pointed out by Sir Jethro Teall as long ago as 1897 (Geol. Mag. p. 554).

A little biotite formed on some of the earlier crystals of magnetite, and, in general, diallage preceded hypersthene.

Finally, it is worthy of note that, although crystallization in the principal member of the norite-complex did not follow the common sequence, the different members of the complex were nevertheless intruded in the normal order: that is, that of decreasing basicity.

(6) Contact-Metamorphism within the Complex.

Some interesting contact-effects have been observed as a result of the invasion of one member of the complex by another. These effects generally took the form of corrosion and recrystallization. Sometimes, however, small quantities of hornblende and biotite were developed; but, apart from these, no new minerals were produced. This is in the main what would be expected, since the composition of any one principal intrusion did not differ very much from that of another.

Such changes as have taken place at the Sierra-Leone contacts are more closely paralleled in certain cases described by Prof. Lacroix[3] from the Central Plateau of France and elsewhere, rather than in any of the British occurrences. Most of the latter refer to the alteration by plutonic masses, not of basic plutonic rocks, but only of basic lavas; and it is uncertain in most instances how far secondary products had developed in the lavas before they were invaded by the new magmas.[4] Consequently, these cases cannot often be taken as good examples of the thermal metamorphism of basic rocks. The British occurrences to which I would

[1] A. Harker, 'The Natural History of Igneous Rocks' 1909, p. 200; and J. V. Elsden, 'Principles of Chemical Geology' 1910, p. 135.

[2] M. L. Nebel, Econ. Geol. vol. xiv (1919) p. 372.

[3] 'Les Enclaves des Roches Volcaniques' Ann. Acad. Mâcon, ser. 2, vol. x (1893).

[4] See A. Harker & J. E. Marr, 'Supplementary Notes on the Metamorphic Rocks around the Shap Granite' Q. J. G. S. vol. xlix (1893) p. 360.

particularly refer are the alteration of basic lavas by the Shap Granite,[1] and of the Eycott lavas by the Carrock-Fell Gabbro[2] and the Eskdale Granite.[3] The changes induced in these cases[4] consist essentially of the conversion of pyroxenes to amphiboles, the recrystallization of the felspars into a mosaic, and the development of brown biotite; locally, garnets, sphene, and other minerals are developed. The Grainsgill Granophyre[5] altered the augite of the Carrock-Fell Gabbro locally into compact brown hornblende, formed granular sphene from the ilmenite and felspar, and converted the felspar into secondary minerals. Examples are given in the Skye Survey Memoir of gabbro enclosing xenoliths (1) of ultrabasic rocks and (2) of an earlier gabbro; in the first case it is stated that no clear indication of thermal metamorphism occurs, and in the second no mention of any alteration is made.[6]

Prof. Lacroix, in the course of his studies on the inclusions of volcanic rocks, was able to consider in detail the effect of basic magmas on coarse-grained basic and ultrabasic xenoliths; but, so far as possible, he satisfied himself beforehand that the xenoliths were still fresh at the time when they were first attacked by the magma. In a later paragraph his results will be compared with those obtained in Sierra Leone. Although in the course of building up the complex described above, the invading magmas themselves did not suffer any appreciable modification, the rocks invaded were nevertheless subjected to a more or less intense contact-metamorphism. The more important examples of this metamorphism occur in the older or normal norite where it has been invaded by:—

(1) A. The younger norite.
B. The beerbachite.

(2) A. The norite-aplite.
B. The dolerite.

The alteration of the older norite effected by (1) the younger norite and the beerbachite, differed from that due to (2) the aplite-veins and the dolerite, in the following important particulars:—

(*a*) Magnitude.—The intrusions of the first group were much larger than those of the second group, and accordingly they were able to incorporate innumerable large and small fragments of the older norite. An examination of these fragments has afforded excellent material for a study of the corrosion

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1 A. Harker & J. E. Marr, Q. J. G. S. vol. xlix (1893).

2 A. Harker, 'Carrock Fell; a Study in the Variation of Igneous Rock-Masses: Part I—the Gabbro' *Ibid.* vol. l (1894) p. 334.

3 E. E. Walker, 'Notes on the Garnet-bearing & Associated Rocks of the Borrowdale Volcanic Series' *Ibid.* vol. lx (1904) p. 102.

4 See also the metamorphism of basalt by Cuillin gabbro, 'The Geology of Glenelg, Lochalsh, & the South-East Part of Skye' Mem. Geol. Surv. Scot. 1910, p. 145; and 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 122.

5 A. Harker, Q. J. G. S. vol. l (1894) p. 334.

6 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, pp. 99 & 121.

of xenocrysts. The results obtained confirm the remarks made above as to the importance of assimilation in certain of the Sierra-Leone intrusives, and are, moreover, of especial interest in that they reveal the mechanism by which an intrusion may, in certain cases, absorb large quantities of the rock which it invades. No xenocrysts have been found, however, in the norite-aplite and the dolerites; consequently, alteration due to these intrusions has to be looked for in those portions of the norite which are near the contacts.

(*b*) Character.—The intrusions of the second group, particularly the norite-aplite, were relatively more acid in composition than those of the first group. Hence the contact-effects of the second group are locally due to the infusion of new material, even more than to the application of heat; this has resulted near the margins of these intrusions in a more intense alteration, combined with the development of new minerals in the norite, especially hornblende and biotite. The alteration produced by the younger norite and the beerbachite, on the other hand, may be ascribed almost entirely to the effect of heat, since any infusion that might have taken place could not have altered the composition of the invaded rock very appreciably.

(1) A. Alteration of norite by younger norite.—The various minerals of the normal norite have been affected as follows:—

(*a*) Felspar.—This mineral shows corrosion and recrystallization, distortion and irregularity of twin-lamellæ, and also a patchy, irregular extinction. Cleavage and other cracks are abundant. The magnetite-microliths of the felspar are sometimes replaced by exceedingly minute, pale-green, rounded grains, and much micrographic felspar and augite are developed, both fine and coarse. The coarse micrographic augite is enclosed in clear felspar, in which twin-lamellæ may sometimes be distinguished. A string of augite-granules, associated with a little magnetite and biotite, frequently runs along the contact between adjacent felspars, and on each side of the string is a narrow zone of clear recrystallized felspar. The fine variety of intergrowth generally originates at the contact of a ferromagnesian mineral with felspar, and then spreads fanwise into the felspar. It should be noticed that the above two intergrowths of felspar and augite occur also in the unaltered norite (see p. 332), in which the coarse variety can frequently be demonstrated to be of primary origin; whereas the fine variety is often secondary (that is, formed shortly after the main period of consolidation of the rock). In the thermally-altered rock, however, these structures are abundantly and characteristically developed, probably because the gentle heat-gradient set up at comparatively low temperatures gave the minerals a better opportunity for growing together in graphic fashion than they had had in the cooling of the main body.

(*b*) Augite.—Outlines are embayed and irregular; there are lines of granules of felspar and magnetite apparently due to crystallization along cracks and in pores [C 120]. A granular recrystallization of the augite may occur. Magnetite is thrown down in abundance; much of it takes the form of long narrow lenticles generally parallel to the cleavage, with numerous thread-like

microliths projecting at right angles. The magnetite occurs also as numerous crystallites and clots; individually these are generally parallel to the cleavages, but they are more closely packed along certain twin-lamellæ. All these features are confined principally to the inner portions of the crystals, since there is generally a narrow outer zone free from them; this outer zone points to renewed crystallization (see Pl. XIX, fig. 4). The normal faint pleochroism of the augite is sometimes increased. A patchy polarization may be produced, generally in bright colours, but sometimes in greys. Flakes of brown biotite appear in some cases [C 172 *b*].

(*c*) Hypersthene.—Magnetite thrown down, both as clots and in coarse dendritic form. The hypersthene is less susceptible to alteration than the augite is.

(*d*) Olivine.—Deeply embayed outlines are common; cracks are unusually numerous, and many of them show ferruginous stains. Much serpentine is produced, particularly near the margins of the crystals. In some cases numerous flakes of biotite are formed around the margins [C 170]; in others, where the olivine has recrystallized in granular form near the edges, small crystals of augite[1] and of hypersthene may be included [C 172 *b*]. Magnetite is frequently thrown down as clouds of dust or in dendritic fashion.

(1) B. Alteration of norite by beerbachite.—The most important feature of this alteration is the extensive corrosion of xenocrysts; olivine and hypersthene, in particular, have been attacked so vigorously that they have been reduced to mere spongy skeletons (see Pl. XIX, fig. 3). Augite also has been actively corroded, with deposition of much iron-ore. Where crystallization has recommenced, however, the augite-crystals have grown again; they have thus acquired wide clear zones free from inclusions of magnetite (see Pl. XIX, fig. 4). No biotite has been detected in this type of alteration. Apart from these features, the contact-action of the beerbachite has been similar to that of the younger norites.

From consideration of numerous xenoliths in the beerbachite, it appears that the various minerals of the norite were dissolved in the following order:—magnetite, felspar, augite, hypersthene, and, finally, olivine. Large magnetite-xenocrysts are rarely seen—they disappear at an early stage; numerous small and more or less rounded xenocrysts of augite may be recognized, and the felspars are in due course reduced to the average size of the beerbachite felspars; hypersthene and olivine are the most resistant, and large spongy masses of these minerals, with their rounded pores occupied

[1] Prof. C. Dœlter has shown that the formation of augite from olivine and felspar is a reversible action; see A. Harker, 'The Natural History of Igneous Rocks' 1909, p. 168.

by granules of felspar and augite, are a common feature of the beerbachite near its contact with the norite. This interesting succession corresponds fairly well with the order of fusibility of these minerals as determined experimentally,[1] and may be compared with similar results obtained by Prof. Lacroix[2] from observations on the behaviour of olivine-nodules and other basic fragments enclosed in coarse basic dolerites.

Lacroix's observations on the manner in which the individual minerals of basic xenoliths are affected by inclusion in a highly heated basic magma do not differ in any important respect from those given above; the chief differences noted in his work are as follows:—

(α) Felspar.—Micrographic intergrowths of felspar and augite are not developed; these minerals recrystallized in granular form.

(β) Hypersthene.—In general, this mineral was converted into granular augite; but sometimes it recrystallized into both augite and olivine.

(γ) Olivine.—Commonly converted into granular augite and magnetite, or into granular olivine; no biotite was developed. A notable feature in the alteration of this mineral was that it frequently recrystallized into a form quite unlike that habitual to it: it assumed the habit of long-bladed crystallites which, elongated in the direction of the C-axis, locally grew parallel one to the other so as to form the skeleton of a large crystal of olivine.

These differences, particularly the greater frequency of fine granular forms in the minerals described by Lacroix, may be ascribed to the fact that the xenoliths studied by this author had been incorporated in a magma crystallizing under volcanic or at most hypabyssal conditions; whereas those considered in the present paper were attacked by magmas subjected wholly to plutonic conditions. Further, the phenomena observed in the Sierra-Leone rocks took place on a much larger scale.

(2) A. Alteration of norite by norite-aplite.—The zone of alteration produced in the norite by a narrow vein of norite-aplite is generally many times wider than the vein itself. The zone may be regarded as consisting of an inner zone, in which the alteration is most intense, and an outer zone, with less intense alteration. The minerals of the two zones are affected as follows:—

Felspar: inner zone.—The crystals are rendered clearer; this is probably due to loss of magnetite-microliths, to the introduction of silica and orthoclase, and also to a certain amount of recrystallization. Further, the twin-lamellæ of the felspars become vague or even indistinguishable, the outlines of the crystals become sinuous, and a curious patchy extinction is developed. The refractive index of the felspar does not, however, fall below that of Canada balsam. Numerous shreds of hornblende are developed.

[1] A. Harker, 'The Natural History of Igneous Rocks' 1909, p. 156.

[2] 'Les Enclaves des Roches Volcaniques' Ann. Acad. Mâcon, ser. 2, vol. x (1893) pp. 483 *et seqq.*

Outer zone. — On the whole, the felspar shows slightly increased turbidity, but many crystals are crossed by clear bands containing granules and microliths of hornblende and pyroxene. The felspar-crystals are, moreover, separated by narrow clear areas in which granules of the ferromagnesian minerals occur. Much additional micrographic felspar and augite is developed.

Augite: inner zone.—This mineral is represented only by plates and spongy masses of green hornblende, crowded with innumerable regularly-arranged microliths and clots of iron-ore; even the iron-ore tends to disappear finally (see Pl. XIX, fig. 5.)

Outer zone.—The augite shows the usual additional precipitation of iron-ore, and moreover is often traversed by brown streaks developed along cracks and along certain twin-lamellæ [C 172 *d*]. These streaks are frequently accompanied by numerous flakes of brown biotite; the flakes, which are often parallel, may extend outwards into the adjacent felspar [C 172 *d*]. The augite is generally fringed with green hornblende, which increases in amount as the inner zone is approached.

Hypersthene: inner zone.—Generally, only the inclusions of iron-ore are recognizable; the mineral itself has been converted into green hornblende.

Outer zone.—Often heavily charged with iron-ore, both in the form of microliths and of a coarse graphic intergrowth with the hypersthene. The mineral shows increasing alteration to green hornblende.

Olivine: inner zone.—The crystals are not recognizable in this zone.

Outer zone.—Much iron-ore is thrown down, with the development of numerous brown and green serpentinous veins. The mineral is sometimes converted into a mesh of yellow-green serpentine, with flakes of brown biotite around the margins [C 172 *d*]. Generally, however, it alters to green hornblende (see Pl. XIX, fig. 6).

(2) B. Alteration of norite by dolerite.—In one specimen [C 72] taken from near the contact, the felspars are turbid and extensively altered, both to calcite and to a colourless mica in the form of minute tufted flakes. The pyroxenes are more or less completely altered to green hornblende; and much magnetite is thrown down as a fine dust along innumerable cracks.

In another specimen [C 172 *b*] hornblende is developed only about the contact; elsewhere the ferromagnesian minerals are largely altered to flakes of brown biotite. Much corrosion of the older rock has taken place, and the junction with the dolerite is very ill-defined. The felspar, for some distance from the contact, shows evident recrystallization, and in its turbidity and minute twin-lamellation it is scarcely to be distinguished from the felspar

of the dolerite. Also, micrographic structures are abundantly developed in the felspar, and granules of augite run along its boundaries. The pyroxenes and the olivine all show more or less complete recrystallization, and they are, moreover, granulated around their margins; the granules along the margins of each mineral are intermixed with those of the other minerals, and also with flakes of biotite.

In conclusion, I wish to express my thanks to Prof. A. H. Cox, of the University College of South Wales & Monmouthshire, Cardiff, to whom I am indebted for many valuable suggestions in the course of this work and also for laboratory accommodation during the examination of specimens.

IV. Summary and Conclusions.

(1) The norite of Sierra Leone constitutes a complex, of which the oldest and most important member is an olivine-norite. The complex forms the mountainous mass which, together with a narrow coastal plain of Pleistocene sediments, makes up the Sierra-Leone peninsula.

(2) The norite differs from other well-known noritic intrusions in its great size, apparent batholithic character, and lack of exposed marginal or basic phases; its junction with older rocks is obscured by the Pleistocene sediments.

(3) The complex is believed to be of very great age, although probably later than pre-Cambrian; it belongs to the West African Magnesian Province.

(4) The main intrusion of norite was invaded in succession by the following related minor intrusions:—(i) norites of slightly different character, which generally possessed a coarser texture; (ii) norite-pegmatite; (iii) beerbachite; (iv) norite-aplite; (v) dolerite.

(5) The first intrusion of norite consists essentially of labradorite, augite, and hypersthene, with varying proportions of olivine and iron-ore (titanomagnetite). The rock is beautifully fresh, and it generally exhibits strong flow-banding. In addition to the intrusions already mentioned, the older norites are cut by segregation-veins, by veins emanating from the younger norites, and by small lenticles of a felspar-olivine rock.

(6) An interesting series of binary and ternary intergrowths of the common minerals has been observed in the norite, indicating the importance of eutectic conditions during the crystallization of the magma. Consequently, there was very often no regular order of crystallization among the principal minerals.

(7) The younger norites form two or more series of intrusions cutting the older norite; but they are collectively of small bulk as compared with the original intrusion. In addition to their greater coarseness, they are as a rule readily distinguished in the field from the older norite by their grey colour and scaly weathered surface, and also by the absence of banding and jointing. In thin

section the younger norites, as compared with the older norite, generally seem to be richer in hypersthene, in iron-ore, and in micrographic intergrowths of felspar and augite; moreover, the felspars of the younger norites are slightly more basic.

(8) The field-relations of the older and younger norites are often very complex, owing to the irregular manner in which the younger rocks broke through the older; highly-corroded xenoliths of the older norite are abundantly included in the younger norites, and there is much evidence to show that the older rock has been incorporated on a large scale in the younger rocks.

(9) The beerbachite intrusions are generally small, and of irregular form. The larger masses actively disintegrated and assimilated the preceding intrusions of norite. The beerbachite consists essentially of fine-grained granular labradorite and hypersthene, with some augite and iron-ore.

(10) The norite-aplite veins occur in the norite in the form of fine threads consisting mainly of quartz and micropegmatite. These threads are, however, only the relatively-acid terminations of wider veins which are sometimes seen to attain a thickness of as much as 9 inches. The thick portions of the veins are light in colour, and possess a pale greenish tinge; they are of medium texture, and consist chiefly of acid soda-lime felspar, orthoclase, quartz, and micropegmatite, with small quantities of pyroxene, hornblende, biotite, and apatite.

(11) The norite-aplite veins were succeeded by a series of more or less ophitic enstatite-dolerite dykes, free from olivine and rich in interstitial acid felspars. In many respects, these dykes closely resemble the well-known British quartz-dolerites; they are, nevertheless, free from quartz and micropegmatite.

(12) Several stages of differentiation may be distinguished in the complex: for instance, deep-seated differentiation, differentiation during intrusion, and differentiation in place.

(13) The older norite was subjected to varying degrees of metamorphism by the younger members of the complex. A resultant effect of frequent occurrence in the norite was the recrystallization of parts of the felspar and augite into a graphic intergrowth of these two minerals. The intrusives more closely related to the norite in composition caused active corrosion and recrystallization, but did not set up new minerals; the relatively acid intrusions, however, such as the norite-aplite and the dolerite, converted the pyroxenes to hornblende and modified the felspars, besides effecting other changes.

(14) Iron-ores occur in the norite only as disseminated grains, as small masses up to several inches in length, and as narrow schlieren; they are highly titaniferous. Sulphides and other economic minerals often associated with noritic intrusions are rare or absent.

(15) Laterite is developed on the rocks of the complex only to a slight degree; it occurs principally on ancient platforms carved into the mass, and on parts of the complex characterized by numerous joints.

EXPLANATION OF PLATES XVI–XIX.

Plate XVI.

Fig. 1. The Sierra Leone Mountains, looking southwards from the summit of Leicester Peak. The photograph shows part of the middle ridge of the mountain-mass with Sugar-Loaf Mountain, capped by a cloud, on the right. Regent village is seen in the upper part of the Orugu Valley on the left of the photograph. (See p. 301.)

2. Contact of coarse norite with older or normal norite, foreshore, near Godrich. The left-hand portion of the photograph shows normal norite, easily recognized by its jointing; in the right-hand portion is seen part of a big intrusion of coarse norite, characteristically free from jointing. (See p. 310.)

Plate XVII.

Fig. 1. Coarse norite invading normal norite, foreshore, near York. The photograph shows fragments of normal norite embedded in coarse norite. The fragments, recognized by a relatively-smooth weathered surface, possess deeply corroded outlines due to the corrosive action of the invading rock; moreover, at the right-hand end of the big block of norite shown in the photograph, there is seen a rock of patchy character due to incomplete assimilation of the fragments by coarse norite. (See p. 312.)

2. Beerbachite invading and incorporating normal norite, Wilberforce Spur. The photograph shows a large residual boulder, about 6 feet long, consisting mainly of beerbachite; on the weathered surface may be seen irregular streaks and patches, due to fragments of normal norite which have been softened, drawn out, and partly incorporated by the beerbachite magma. (See p. 315.)

Plate XVIII.

Fig. 1. Normal norite [C 3], summit of Leicester Peak. A large fresh crystal of olivine is cut by the lower end of the vertical wire, and two crystals of schillerized diallage are cut by the horizontal wire; hypersthene partly enwraps the olivine and diallage. The clear mineral is labradorite. In the top left-hand quadrant is part of a crystal of labradorite which is completely enclosed in diallage and hypersthene; the labradorite of the central part of the section is later than the hypersthene. Several grains of iron-ore are enclosed in hypersthene. Ordinary light. $\times$ 28. (See p. 325.)

2. Beerbachite [C 93], Wilberforce. The following minerals are present, mostly in granular form:—pyroxenes, chiefly hypersthene, felspar, and black iron-ore. Some of the pyroxenes possess idiomorphic outlines. The minerals show a slight tendency to parallelism. Ordinary light. $\times$ 28. (See p. 326.)

3. Norite-aplite [C 172 *a*], near York. The photograph shows much fine micropegmatite and also two large crystals of acid plagioclase, one of which possesses two sets of twin-lamellæ intersecting at right angles. Small patches of felspar with twin striæ are enclosed in the micropegmatite. The plagioclase, as well as the orthoclase, is seen to be graphically intergrown with the quartz. At the intersection of the cross-wires is a fine spongy mass of enstatite, and adjacent to it, in the lower right-hand quadrant, is another mass which is of somewhat less dense texture; the second mass consists of minute, more or less parallel, prisms of enstatite, all embedded in a plate of felspar which shows fine twin-lamellæ. Crossed nicols. $\times$ 28. (See p. 322.)

Fig. 4. Enstatite-dolerite [C 163], south of York. The section consists principally of zoned plagioclase and augite. In the top left-hand quadrant is a patch of clear untwinned felspar, enclosing grains of pyroxene and numerous small needles of apatite; also it partly encloses an irregular plate of augite. Interstitial to the laths and prisms of plagioclase, and also enclosed in the areas of clear felspar, is much granular pyroxene, in the form of both common augite and enstatite. The felspar-prisms each consist of turbid labradorite surrounded by a narrow zone of clear felspar. In the lower half of the figure is a spongy mass of iron-ore. Ordinary light. × 28. (See p. 324.)

5. Primary intergrowth (binary) of felspar and augite [C 68], Lumley. The figure shows fine and coarse grains of augite embedded in clear labradorite. The bigger grains, arranged in rude graphic fashion, are in optical continuity with the augite that encloses the large plates of magnetite. Ordinary light. × 28. (See p. 331.)

6. Primary intergrowth (ternary) of felspar, augite, and magnetite [C 68], Lumley. The minerals depicted are felspar (white), augite (dark grey), and magnetite (black). The magnetite is largely enclosed in augite that shows characteristic cleavage. Parallel tongues of augite, each enclosing a rod of magnetite, project into the felspar. Near the intersection of the cross-wires, in the upper right-hand quadrant, the ternary intergrowth is beautifully developed in the form of fine parallel rods of the three component minerals. In several parts of the slide the augite is seen to be graphically intergrown with the felspar. Ordinary light. × 28. (See p. 333.)

Plate XIX.

Fig. 1. Corona-like intergrowth of felspar and augite [C 68], Lumley. The intergrowth was formed later than that shown in Pl. XVIII, fig. 5. The minerals depicted are labradorite (pale grey), the intergrowth (dark grey), and magnetite (black). The clear spaces represent fragments of the slide that have broken away. The intergrowth is seen spreading fan-wise into the felspar from the contact of this mineral with the magnetite. The felspar-crystal enclosed in the magnetite has been largely replaced by the intergrowth. Ordinary light. × 28. (See p. 331.)

2. Graphic intergrowth of hypersthene and magnetite, normal norite [C 1], Leicester Peak. The minerals depicted are the following:—felspar (white), with faint cleavage-cracks; olivine (pale grey), with thick irregular cracks; hypersthene (medium grey), with a fine parallel cleavage; augite (dark grey), locally almost opaque with schiller inclusions; and magnetite (black). In the central portion of the section, with a large crystal of olivine on the left and a smaller crystal of augite on the right, is an irregular plate of hypersthene in which abundant graphic magnetite is embedded. The magnetite appears also as large plates in the hypersthene. Ordinary light. × 28. (See p. 332.)

Figs. 3 & 4 illustrate the alteration of norite by a magma of similar composition; namely, beerbachite.

3. Corroded xenolith of olivine and hypersthene in beerbachite [Mount Aureol, No. 3]. The left-hand half of the section consists mainly of olivine, and the right-hand half mainly of hypersthene. These minerals have been so extensively corroded that they now form merely a spongy network with interstices

occupied by granules of felspar. The hypersthene has largely recrystallized in granular form; it contains much magnetite, of which some at least has been thrown down as a result of thermal metamorphism. The olivine has recrystallized locally, but only to a slight extent. Along its contact with the hypersthene the olivine has been converted into serpentine; this serpentine appears black in the photograph. Magnetite has been thrown down along cracks in the olivine. Ordinary light. × 28. (See p. 339.)

Fig. 4. Corroded augite-xenocryst in beerbachite [C 101], Wilberforce.—The minerals seen here are felspar, pyroxene, and magnetite. The augite-xenocryst, derived from the norite, underwent much corrosion; in the course of this corrosion the crystal was rendered almost opaque by the deposition of much iron-ore in the form of schiller-inclusions. Then, as the enclosing magma began to crystallize, a clear outgrowth formed around the xenocryst; this outgrowth is in optical continuity with the augite of the original crystal. Ordinary light. × 28. (See p. 339.)

Figs. 5 & 6 illustrate the alteration of norite by a relatively-acid magma: namely, norite-aplite.

5. Alteration of augite by norite-aplite [C 116*a*], near York. In the centre of the field of view is a crystal of augite which has been almost completely replaced by hornblende in the form of ragged green plates; remnants of the original crystal may still be seen as small light-coloured shreds. Numerous grains of iron-ore are scattered through the crystal; they were thrown down as a result of the alteration. In the lower part of the figure the pseudomorph is seen to be in communication with a small vein of norite-aplite that was chiefly responsible for the alteration. The felspar shown in the figure has also been considerably modified; it has on the whole become less turbid, although numerous inclusions have developed in it. In the upper left-hand quadrant is a patch of turbid felspar which shows only slight traces of alteration. Numerous shreds and small spongy masses of hornblende are enclosed in the felspar; at least some of these represent augite which originally had been intergrown with the felspar in graphic form. Ordinary light. × 28. (See p. 341.)

6. Alteration of olivine in norite [C 172*d*], near York. An altered crystal of olivine is seen in the centre of the field of view; part of another similar crystal is seen in the upper left-hand quadrant. The olivine has been rendered almost opaque by the deposition of much magnetite in the form of dust and small grains. Around the margins the olivine has been largely replaced by flakes of brown biotite, as may be seen in the upper right-hand quadrant and along the lower margin of the crystal of olivine. An interesting feature of this contact-alteration of the norite is the abundant development of micrographic felspar and augite, which in the present instance almost completely surrounds the altered olivine, and spreads more or less fan-wise into the adjacent felspar. The intergrowth takes the form of small curved rods and blebs of augite embedded in felspar. Ordinary light. × 28. (See p. 341.)

Discussion.

Dr. J. W. Evans expressed his sense of the value of this paper, which described an intrusion of norite of unusual size and exceptional characters. The comparatively fine grain of the main intrusion might be explained by the fact that its present form corresponded approximately to its original contours. The subsequent intrusions might owe their coarser texture to the fact that the mass into which they were intruded was still hot. It would have been more satisfactory if the contact of the norite with the surrounding rocks could have been investigated by means of borings through the alluvium, but that was impracticable at the present time.

Mr. A. E. Kitson congratulated the Author on the valuable work that he had done in Sierra Leone. He agreed with the view that the norite-mass of the Colony had probably been intruded along a zone of faulting, and thus had determined to some extent the character of the coast-line of this part of West Africa.

Since the norite-mass had not been foliated, he believed that it was later than pre-Cambrian in age. The remnants of old platforms showed strong evidence of at least four successive uplifts, aggregating more than 1000 feet above sea-level. He agreed with the Author that there had been a good deal of assimilation of the older norite by the younger intrusions. Examples of assimilation, though of different rocks, occurred in the Gold Coast. He added that it was interesting to note that, although in the area between Freetown and the Hill Station there was a considerable amount of bauxitic 'laterite,' he had not seen any blocks of bauxite.

The Author thanked the Fellows present for the kind reception given to the paper, and the speakers for their remarks. With reference to Dr. Evans's observation concerning the coarse texture of the younger intrusions, the Author thought that this texture was accounted for, not only by the fact that the younger norites were intruded into a mass that had not entirely cooled down, but also by the fact that they were themselves probably of considerable size, although commonly giving rise only to small outcrops. Also, when intruded, they had sufficient reserve of heat to incorporate the older rock in considerable amount. Finally, the coarser texture was possibly induced by a slight difference in composition, much as in the case of the succeeding intrusions of norite-pegmatite, which were even coarser in texture. In reply to Mr. Kitson, the Author stated that iron-ores occurred in the younger norites much as in the older norites, except that in the former they were present only as grains and small segregations, and not as *schlieren*. Also, bauxite occurred in small amount on outcrops of both the older and the younger norites.

12. *The* Nature *and* Origin *of the* Pliocene Deposits *of the* County *of* Cornwall, *and their* Bearing *on the* Pliocene Geography *of the* South-West *of* England.

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Contents.

I. Introduction.

The present paper deals more particularly with the petrography of the younger Tertiary deposits of Western Cornwall which, by reason of their mode of occurrence and lithological similarity to the well-known fossiliferous beds of St. Erth, have been generally assigned to the Pliocene age. These deposits occur as isolated patches of detrital material resting in eroded hollows in Palæozoic or older rocks in the south-western part of the county, and are located at St. Agnes, 4 miles due south-west of Perranporth; at St. Erth and Canons Town in the Hayle-River valley; at Crousa Common, a mile and a half south-west of St. Keverne (Lizard district); and at Polcrebo, near Crowan, 4 miles south of Camborne, where an outcrop of gravels of alleged Pliocene age is found. With the exception of the St. Erth Beds, no fossils have hitherto been discovered in these deposits, and their stratigraphical position has been inferred entirely from general geological and topographical considerations.

The object of this paper is not only to establish the relative ages of these deposits by petrographic methods, but to demonstrate the importance of this mode of attack in problems of stratigraphical correlation where palæontological evidence is in some cases lacking. In addition, the mineralogical factors concerned are used as a guide to the determination of the origin of these sediments and, in conjunction with topographic data, to restore the geography of this part of Britain in early Pliocene times, in so far as the evidence at our disposal allows.

II. Mode of Occurrence of the Deposits.

(*a*) St. Agnes.

Flanking the northern part of St. Agnes Beacon, and having the form of a crescent-shaped outcrop, the Pliocene deposits are here resting on a belt of metamorphosed Ladock Beds (Lower Devonian) surrounding the St. Agnes granite-mass, except in the extreme south-western corner where they abut on the granite itself. The height of the Beacon is 628 feet O.D., and, as we descend the northern slope, the deposits are first met with approximately along the line of the 420-foot contour, whence they are continuous down a gentle gradient to the 350-foot level. Both the upper and the lower limits of the outcrop are concealed by several feet of 'Head.' a conspicuous feature of the Quaternary geology of this region, and consequently the actual contacts between the sands and the underlying rocks are everywhere hidden.

In addition to several minor natural exposures of the sands and clays, which here, as elsewhere, constitute the principal facies of these deposits, there are several overgrown pit-sections visible; while two more recent pits giving greater facilities for study occur: one at Higher Bal, half a mile west of St. Agnes Church, and the other at Beacon Cottage, at the foot of the Beacon on the south-western side. In the former case about 12 feet of clay and sand are now seen overlain by 3 to 4 feet of 'Head'; in the latter exposure only 10 feet of grey clay are seen, the section being now much obscured. The older sections mentioned by Sir Henry De la Beche[1] and quoted by Clement Reid[2] are certainly no longer in existence, and are either quite overgrown or obliterated by waste-material thrown out from the adjacent mines.

(*b*) St. Erth.

On the eastern side of the Hayle-River valley, and situate about half a mile from the river itself, at the village of St. Erth, is the classic occurrence of Pliocene deposits, so well known for their peculiar (indeed, in this country, unique) fauna. The actual boundaries of the outcrop are again somewhat difficult to define precisely, on account of the thick capping of 'Head' developed. Roughly elliptical in shape, about half a mile long and a quarter of a mile broad, the St. Erth sands lie on a gentle valley-slope between the 170- and the 50-foot contours; the mass has a discernible north-easterly and south-westerly strike, and is bounded by a well-marked quartz-porphyry dyke ('Mellanear' or 'Long-Rock' elvan)[3] on the north-west, and by an elongated sill of greenstone on the south-east, both intrusions having this dominant

[1] 'Report on the Geology of Cornwall, Devon, & West Somerset' 1839, pp. 258–60.

[2] 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, pp. 66–67.

[3] 'The Geology of the Land's End District' Mem. Geol. Surv. 1907, pp. 63–64.

FIG. I. SKETCH-MAP OF THE SOUTH-WEST OF ENGLAND.

Depicting approximate land-surface above sea-level in early Pliocene times (dotted), the distribution of the late Palæozoic granite intrusions (shaded), and the probable courses of the sediment-bearing currents from north-east and south-west. Unshaded areas represent the present land-surface below 400 feet O.D.

Scale:-18 miles to 1 inch.

strike direction. Between the dyke and the sill is the basin-shaped depression in the Mylor Slates (Lower Palæozoic) in which the deposits were laid down, and thus we can explain the disposition of the sands in a north-easterly and south-westerly direction at this place. Natural sections in these deposits are rare, and evidence for mapping has to be based largely on quarry-exposures, on the character of the soil, and on topographic data. The artificial sections at present visible differ greatly from those examined even 14 years ago, when the Geological Survey Memoir of the district was first published; in no case is the fossiliferous clay to be seen now, and, of the three exposures available for study, that of the Cornish Sand Company's pit (an enlargement of the better known 'Harvey's Pit)[1] is by far the best. This pit is situated immediately south of and adjacent to the road leading from the village to the vicarage. The old pits west of the vicarage, in which the fossils were originally obtained, are now much overgrown, and all traces of the fossiliferous clays obscured.[2]

The Cornish Sand Company's pit, which has been rapidly extending during the last few years, shows an excellent section in the Pliocene sands. The character of these deposits varies considerably both laterally and in depth, and apart from minor irregularities in bedding, there is a marked dip of the whole series of 5° north-westwards which determines the gentle slope of the fields between the vicarage and the village, and further explains the non-appearance of the fossiliferous clay in this pit. The section shows an average thickness of 20 feet of sand resting upon the eroded Palæozoic floor, which consists of slate intersected in one place by an 'elvan' dyke. The sand is overlain by 2 to 4 feet of 'Head' and surface-soil.

The late Clement Reid, writing in 1890,[3] suggested that possibly a similar outcrop to that of St. Erth would be ultimately discovered on the watershed separating the Hayle River from the streams draining into Mounts Bay at Newtown; but careful search, both here and at likely horizons throughout the whole valley from north to south, failed to reveal any trace of Pliocene material other than that recorded by the Geological Survey as occurring at Lelant Downs, half a mile north of Canons Town, 2 miles west-north-west of St. Erth. In this case the evidence of outcrop, though indefinite, is certainly in favour of the occurrence of a small patch of Pliocene deposit resting upon metamorphosed Mylor Slate at a height of about 150 feet above O.D., and having much the same topographical aspect as the St. Erth Beds opposite. No pits have ever been dug in this deposit, and the only evidence obtainable is from the sandy nature of the soil and from a few blocks of ferruginous sandstone found occasionally on the valley-slope.

1 Mem. Geol. Surv. 1907, p. 72.

2 At least 5 feet of sand and rubbly surface-material now filling the pits would have to be removed before exposing the clay again, even if the thick and overgrown vegetation were cleared.

3 'The Pliocene Deposits of Britain' Mem. Geol. Surv. p. 60.

(c) St. Keverne.

Resting on the Lizard 'platform' at a height of 364 feet above O.D., and situated a mile and a half due south-west of the village of St. Keverne, are the Crousa-Common gravels first noticed by Sir Henry De la Beche in his report of 1839. Unlike the similar deposits of St. Agnes and St. Erth, the extent of this outcrop is easy of definition. It consists of a rectangular mass 1 mile long by half a mile broad, lying upon the eroded surface of the Lizard gabbro, the conspicuous feature of this area. As Mr. J. B. Hill has pointed out,[1] the extent of the deposits is naturally defined by the sharp change in vegetation noticeable as the boundaries between the sands and the igneous rocks are traversed; in the former case the marked development of gorse, heather, and pine contrasts strongly with the more fertile grassy soil yielded by the gabbro, and the typical weathered blocks of this rock scattered everywhere over the surface of its outcrop constitute a further element of differentiation between the two.

Both natural and artificial sections in these sands are common, but only one pit is at present worked, the others being overgrown and often under water. The best exposure is that in a shallow quarry adjoining the main road to St. Keverne. immediately east of the 9th milestone from Helston. This pit shows a section of coarse sands and gravels varying from 8 to 10 feet in thickness, and capped by a few inches of mixed surface-detritus and peaty soil. The deposits are remarkable for their varying texture, the strong current-bedding exhibited, and for the quantity of big pebbles and even boulders associated with them. Their base is not seen in this particular pit, although it cannot be far below the floor of the present working (1920), as in wet weather the pit is badly flooded, pointing to the existence of impervious clayey rock at no great depth, such as would be yielded by the superficial decomposition of the gabbro. In some of the older abandoned pits on the north side of the road in the wood, blocks of gabbro may be seen in dry weather protruding from underneath the sandy floor, thus showing the vertical extent of the deposits.

No fossils have ever been found in the Crousa-Common deposits, and their Pliocene age has been inferred from their relations to the Lizard 'platform,' a remnant of the characteristic Pliocene features of the West Country.

(d) Polcrebo.

The curious pebble-bed found at Polcrebo near Crowan, 4 miles south of Camborne, originally described by W. Tyack[2] and later referred to by Mr. J. B. Hill,[3] is of very limited extent; it consists principally of well-rounded pebbles of quartz, resting at a height

[1] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 230.
[2] Trans. Roy. Geol. Soc. Cornwall, vol. ix (1875) p. 177.
[3] 'The Geology of Falmouth & Camborne' Mem. Geol. Surv. 1906, pp. 88–89.

of 480 feet upon an eroded granite-surface, and is of very obscure origin. Beyond the doubtful topographical evidence as to its alleged Pliocene age, there is little whereby to reconcile its suggested relationship to the St. Agnes, St. Erth, or Crousa-Common deposits.[1]

III. Methods of Investigation.

In all cases the individual outcrops of the deposits were sampled both laterally and vertically: in the first instance, suitable exposures were located along the strike of the beds, from which samples were taken at regular intervals if outcrops allowed; in the second case all the principal quarry-sections at each locality were visited, and the sands sampled from top to bottom at intervals depending on the lithological variations noted in the beds. As an example of this method of procedure we may take the St. Erth occurrence—in a lateral distance of some 800 yards measured along the strike of the beds, four samples were taken at approximately equal intervals of 200 yards, the material being furnished by stream, hedgebank, and quarry. For sampling in depth, the Cornish Sand Company's pit was chosen, since it showed the maximum vertical section exposed in the beds at the time. In this case samples were taken from 6, 8, 14, 20, 22, and 23 feet below the surface, these horizons representing the more marked lithological variations in the deposit as seen in this pit. The samples referred to in all instances consisted of about 200 grammes of material, having regard to the average grade-size of the particles, about 0·2 mm. In the case of much coarser material, as at Crousa Common, at least 500 grammes were taken for each sample, in order to ensure a reasonable yield of 'heavy' residue.

The usual method of procedure for the qualitative examination of the mineral constituents of the deposits was adopted; the samples were first sifted free of the larger grains and pebbles, by using a 30-mesh sieve and later a 60-mesh sieve; in this way each sample was divided into three rough grades, a coarse, medium, and fine. The coarse material, rejected by the 30-mesh sieve, included the grains greater than approximately 0·5 mm. in diameter; the medium material, passed by the 30-mesh but rejected by the 60-mesh sieve, included the grains between approximately 0·25 mm. and 0·5 mm., while the fine material, passed by the 60-mesh, included all fine sand, silt, and clay: that is, particles less than 0·25 mm. in diameter. It is desirable to emphasize that such grading is only of a very approximate character, and is used solely for convenience in qualitative work, but not for accurate mechanical analysis, which must be obtained by the ordinary methods of elutriation; it is of use, however, in giving a rough impression of the relative proportions of the particles between the chosen limits.

[1] *Ibid.* p. 88; also Trans. Roy. Geol. Soc. Cornwall, vol. ix (1875) p. 181.

The coarse material was first carefully examined with a lens, and subsequently with the microscope, in the latter case by placing some of the grains on a black card and viewing them by reflected light. The medium and fine material were both washed with water, treated with a dilute solution of hydrochloric acid so as to remove any ferruginous coating of the grains, and in the case of the fine grade, boiled previously with a 1 per cent. solution of sodium carbonate to deflocculate silty and clayey matter. The clean sand was then dried, and about a third taken for treatment with 'heavy' liquids. (A preliminary trial in all cases showed that these Pliocene deposits yielded abundant residue, and consequently there was no necessity for utilizing the whole of the cleaned sample, except for quantitative determination.)

For the 'heavy' mineral concentration bromoform of specific gravity 2·82[1] and, in special circumstances, cadmium borotungstate of specific gravity 3·28 were used. The residues thus obtained were separated with an electromagnet into magnetic and non-magnetic crops; these were then mounted in Canada balsam for microscopical examination, and a slide was made in each case of the 'light' material of the sample, s.g. $< 2{\cdot}82$. The total amount of 'heavy' mineral concentrate obtained in all cases was mounted, to ensure inclusion of the rarest mineral species present in the sediment.

In many instances the samples were examined quantitatively, and the percentages of light material, ferruginous cement, silt and clayey matter, and 'heavy' residue determined. Such results are included below in the section dealing with the petrography of the various deposits.

IV. Lithological Character of the Deposits.

(*a*) St. Agnes.

The deposits here consist of a well-marked series of yellow, white, and brownish-red sands overlain by grey and mottled clays. The principal section exposed at Higher Bal, west-north-west of St. Agnes Church, shows about 6 feet of sand, yellow at the base, and passing up into an almost pure white sand, which gives place to a brownish-red facies immediately beneath the clay. The transition from the sand to the clay is actually not so sharp as at first sight appears, and an intermediate arenaceous clay separates the sands below from the true clays above. The sandy clay and overlying grey and mottled clays in this section vary from 7 to 8 feet in thickness, although this facies tends to thicken south-westward; as in the Beacon Cottage pit no sand is exposed, and 8 to 10 feet of clay occur. The sands themselves occasionally

[1] Since the War, the bromoform put on the market has varied considerably in purity, and the specific gravity has fluctuated accordingly; in some cases it was possible to raise the gravity to 2·9 by repeated distillation, but not without great trouble and a certain amount of loss.

yield interesting well-worn quartz-pebbles, quartz-veined 'killas' pebbles, rounded schorlaceous fragments, and (more rarely) rounded pebbles of cassiterite.[1] A few coarser grit-bands are present in the red sand, but they are essentially local and discontinuous.

(*b*) St. Erth.

Here again the clay and sand facies are both developed in these deposits, although unfortunately we are no longer able to study the former *in situ*; for the old section in the Vicarage pit at St. Erth, in which the fossiliferous clay occurred (see p. 351), we must refer to Prof. P. F. Kendall & R. G. Bell's diagram in their paper dealing with the Pliocene fauna of this deposit.[2] From the details given it is evident that the section showed a few feet of 'Head' capping about 6 feet of yellow sand overlying the clay; the latter rested upon a much thicker band of 'fine quartzose sand' persistent to the base of the series. Unfortunately, the authors of this paper omitted all details as to thickness of these beds; but, from particulars given by Clement Reid,[3] and from the section which it is now possible to measure in the uppermost yellow sand at the Vicarage pit, it would seem that the clay varied from 7 to 8 feet in thickness, and the underlying sand from 10 to 12 feet in thickness. The pit now only shows about 5 feet of the uppermost yellow sand.

The St. Erth sands vary lithologically in much the same manner as those of St. Agnes do: the same yellow, white, and brownish-red facies, with an associated grit-band, are present, and the last-mentioned contains several small pebbles of quartz, killas, greenstone, and schorlaceous material; this grit-band, although quite conspicuous where it does occur, is non-persistent and of little value as a definite horizon. Other seams of pebbles are scattered promiscuously throughout the red sand; such pebbles are always well worn and by far the greater percentage consists of quartz. A loamy sand underlying the grit-band is a well-differentiated facies, of a consistency contrasting markedly with the white and yellow sand above; it constitutes the best moulding-sand from the pit, and is of importance on that account. Current-bedding in this series is not a well-marked feature, although it may be detected in some instances on a small scale; in this respect, we may note a further similarity to the St. Agnes deposits. On the whole, the St. Erth deposits are of finer texture than those of St. Agnes or St. Keverne, particularly the last-named; their general lithology suggests deposition in deeper water than in the other cases.

The lithological character of the deposit alleged to occur on the opposite side of the valley at Lelant Downs, has already been mentioned (p. 351).

1 'The Geology of the Country around Newquay' Mem. Geol. Surv. 1906, p. 64.

2 Q. J. G. S. vol. xlii (1886) fig. 1, p. 202.

3 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, pp. 59 *et seqq.*

(*c*) St. Keverne.

In the Crousa-Common gravels there is a much wider variation noticeable, and the deposits are coarser and more heterogeneous in composition than in the preceding cases. The material consists largely of subangular fragments of quartz, occurring both as grains 0·25 mm. in diameter and as pebbles 2 or 3 inches in diameter, with every intermediate grade present; associated with the quartz are pebbles of slate of the 'killas' type, schorlaceous fragments, and pebbles of rocks recognizable in the Lizard series. Impersistent seams of finer sand and occasionally grey clay accompany the gravels, but they are by no means common. Reference must be made to the contortions and local folds exhibited by these gravels: this feature is certainly most striking in the pit adjacent to the main St. Keverne road (p. 352); but it would seem to be more easily explicable as due to current-bedding of coarse detritus in shallow water, than as the result of later subsoil movements.[1] The coarse texture and the very mixed character of these deposits tend to accentuate such inequalities of bedding; but, when examined closely, their true neritic character is quite apparent. The amount of material that has to be sifted in order to produce a sand concentrate for petrographical investigation is more than double that used in the other cases; this in itself bears testimony to the nature of these gravels.

(*d*) Polcrebo.

Mr. J. B. Hill has already pointed out a similarity existing between the Polcrebo gravels and those of Crousa Common, in so far as the quartz-pebbles are concerned, a feature remarked by W. Tyack in his original description of the former deposit.[2] The greater mass of the Polcrebo material is quite unlike that of Crousa Common, however, and consists of well-worn rounded pebbles of quartz and granite, the latter of local origin. These pebbles are extremely variable in size; Tyack says that 'they are of all sizes, from boulders as large as a pumpkin to pebbles as small as hazel-nuts.' Sand in association with the gravels is of rare occurrence, and what fine-grained material (2 mm. in diameter) there is, has been derived solely from the weathering and disintegration of the pebbles themselves. But for their elevation at 480 feet above sea-level, there is little lithologically to suggest a relationship to the deposits under consideration, although their mode of occurrence is certainly significant.

[1] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 230.
[2] Trans. Roy. Geol. Soc. Cornwall, vol. ix (1875) p. 175.

V. Petrography of the Sediments.

(*a*) St. Agnes.

The determination of the mineralogical composition of the St. Agnes deposits yielded the following results:—

	Horizon	I.	II.	III.	IV.
Light Material: S.G. < 2·82.	Minerals.				
	Quartz	Essential constituent throughout.			
	Kaolin	—	—	4	4
	Muscovite	4	4	5	4
	Glauconite	4	4	1	3
	Ferruginous cement	Essential authigenous material.			
Heavy Residue: Magnetic. S.G. > 2·82.	Magnetite	7	7	7	7
	Ilmenite	5	5	5	5
	Garnet	—	—	—	—
	Tourmaline	8	8	8	8
	Staurolite	3	1	3	3
	Epidote	4	4	—	4
	Chlorite	1	2	2	2
	Biotite	1	2	2	2
Heavy Residue: Non-Magnetic. S.G. > 2·82.	Leucoxene	7	7	7	7
	Zircon	4	6	5	5
	Kyanite	6	5	1	6
	Anatase	—	—	2	2
	Rutile	2	4	2	2
	Brookite	—	—	—	—
	Topaz	4	5	5	5
	Andalusite	7	5	8	7
	Muscovite	5	5	6	5
	Corundum	—	—	?	?
	Cassiterite	1	—	1	1
	Xenotime	?	—	? 1	? 1

[9 = 'Flood' of a particular species. 8 = Very abundant. 7 = Abundant. 6 = Very common. 5 = Common. 4 = Scarce. 3 = Very scarce. 2 = Rare. 1 = Very rare.]

I. Yellow Sand. Base of series now exposed, 15 feet below the surface, quarry at Higher Bal.

II. Red Sand. 12 feet below the surface, quarry at Higher Bal.

III. 'Candle Clay.' Average of several samples taken laterally, including quarries at Higher Bal and Beacon Cottage.

IV. Average composition of the St. Agnes deposits.

The residues yielded by all the members of the St. Agnes deposits are characterized by the abundance of the magnetic minerals as compared with the non-magnetic, and the bulk of this magnetic crop consists of tourmaline and iron-ores. In the case of the red sand, the actual proportions are 0·81 per cent. magnetic to 0·036 per cent. non-magnetic. The 'light' material is mainly

quartz, which in the case of the sands constitutes about 94·1 per cent. of the facies; associated with the quartz are kaolin, muscovite, glauconite, and authigenic matter, chiefly limonite in the yellow sands, and hæmatite in the red sands. In the clays the percentage of mica and kaolin is higher, though much of the material is an indeterminate 'paste,' probably consisting of quartz, sericite, chiastolite, rutile, and iron-ores; the mottling of these clays is due to variations in the degree of secondary oxidation undergone by the original iron-compounds.

Description of the more important Mineral Species.

Quartz.—This mineral occurs in subangular to well-rounded grains, usually coated with ferruginous cement. On clarification with acid, the grains are seen to be highly turbid, owing to inclusions of apatite, tourmaline, and rutile. No fluid cavities were noted in the grains.

Muscovite.—Varies considerably in composition. The 'light' material (S.G. $< 2\cdot82$) presents fairly-clear irregular flakes of low polarizing character, usually showing good interference-figures. The denser facies which sinks in bromoform is turbid with inclusions of ferric oxide, tending to parallel arrangement within the flakes.

Magnetite is a noteworthy constituent of all facies of the deposit, and occurs in subangular grains; rounded octahedra are rare, though noted more in the red sands than in the other facies. In the clays, sharply angular fragments are seen (magnetite dust), of a brilliant silvery-grey colour by reflected light.

Ilmenite.—Owing to the absence of well-individualized magnetite, some little difficulty is experienced in differentiating ilmenite from that mineral; the abundance of leucoxene in the non-magnetic residue, however, is some measure of the proportion of original ilmenite, though in many cases rounded irregular grains of the species are clearly defined by their dull reddish-grey lustre in reflected light.

Tourmaline is exceedingly abundant, and in the yellow and red sands constitutes the greater part of the residue. It usually occurs as large, irregular, and rounded grains, of blue, green, brown, intermediate shades, and parti-coloured. The brown varieties show the strongest pleochroism, and many of the grains, being basal, exhibit uniaxial interference-figures. Besides the grains (though by no means so common), well-formed prisms are seen, generally striated, and having rhombohedral terminations and basal partings; doubly terminated varieties are rare. Such prisms are usually blue, green, or bluish-green, and are pleochroic: they have an average length of 0·3 mm., while the grains frequently measure 0·25 mm. along their greatest length.

Staurolite.—Only a few grains of indubitable staurolite were recognized, although the mineral may actually occur in greater proportion, or at least with more constancy than is to be inferred from the determinations made. The grains are well rounded, but characterized by their deep brownish-yellow colour, making distinction between them and the abundant brown tourmaline a difficult matter. The weaker pleochroism and higher refractive index than the tourmaline were noted; but the most reliable differentiating factor was the biaxial positive interference-figure revealed in some cases.

Leucoxene.—Abundant and occurring in dull whitish-grey pellets (as seen by incident light), well rounded, with occasionally a core of unaltered ilmenite. The grains have a rough and pitted appearance, and are frequently stained brown.

Zircon.—Two very distinct varieties of zircon occur, well-rounded doubly-terminated prisms averaging 0·3 mm. in length, and short, 'stumpy,' but well-defined prisms with irregular terminations. The former type is usually full of inclusions, and is more characteristic of the basal yellow sands; the latter variety is almost transparent with only occasional fluid (?) cavities, and is more typical of the red sands and clay. The scarcity of this mineral at the base of the series, its common occurrence at the middle horizons, and its gradual diminution in proportion as the upper beds are reached, considered together, are noteworthy features.

Kyanite.—These crystals are certainly distinctive, and occur as elongated prisms determined by the (100) cleavage and (001) parting: traces of a well-marked (010) cleavage are nearly always present; the grains have suffered much abrasion, and are on the whole extremely well rounded. They strongly resemble analogous grains found in the Lower Greensand. (Fig. 3, p. 371.)

Anatase.—Absent in the sands and occurring but rarely in the clay as indigo-blue tabular crystals perfectly formed. Probably secondary, derived from the decomposition of ilmenite.

Rutile.—This mineral is not so common as might be expected, and well-formed crystals are rare. Generally it occurs in well-rounded 'foxy' red grains, rudely prismatic, measuring 0·25 mm., and void of any pleochroism.

Topaz.—Well-rounded, clear, and transparent grains of topaz are characteristic of the red sands and clay, but less common in the yellow sand. The grains are variable in size, measuring from 0·1 to 0·2 mm. in diameter, but occasionally attaining 0·5 mm. They are easily distinguishable from the andalusite by their transparency, absence of pleochroism, and by the biaxial positive interference-figures exhibited by many of them.

Andalusite.—This mineral constitutes the most important, and at the same time the most interesting, feature of the St. Agnes deposits. It occurs both as irregular rounded grains and as well-formed prismatic crystals, and in most cases exhibits characteristic blood-red pleochroism, more intense and striking than in the case of any other known occurrence of the mineral in British sedimentary strata. The 'rounded grain' type, which is the commoner mode of occurrence, presents marked subconchoidal fractures, and is usually less turbid with inclusions than the crystals; the latter consist of well-formed rhombic prisms terminated by (011) faces or by the basal pinacoid; grains flattened parallel to (001) are normal to the acute bisectrix, and show biaxial negative interference-figures. The inclusions are mainly quartz, graphite, and magnetite, and in some cases secondary alteration-products are developed, the chief of which has been recognized as kaolin. The pleochroism and usually turbid character of the mineral serve to differentiate it easily from the associated topaz, to which it is only subordinate in quantity in the red-sand horizon.

Cassiterite.—This mineral is by no means common, and no trace of it was found in the red sand. In the basal sands and also in the clay, however, one or two dusky-brown, rounded, tetragonal crystals were observed, measuring about 0·2 mm. in length.

(*b*) St. Erth.

As stated previously (p. 353) six definite lithological horizons were recognized in the St. Erth sands, in the vertical section shown in the Cornish Sand Company's pit; but only the upper yellowish-brown sand was traceable laterally. The following table

shows the results of the microscopical examination of the various facies:—

	Horizon	A.	B.	C.	D.	E.	F.	G.
Light Material: S.G. $<$ 2·82.	Minerals.							
	Quartz	Essential and dominant constituent throughout.						
	Kaolin	5	5	5	5	5	5	5
	Muscovite	6	6	4	4	4	5	4
	Glauconite	4	4	4	3	4	3	4
	Ferruginous cement.	Essential authigenous material throughout.						
Heavy Residue: Magnetic. S.G. $>$ 2·82.	Magnetite	7	7	7	5	6	6	7
	Ilmenite	5	7	5	5	6	5	5
	Garnet	1	1	1	—	—	—	1
	Tourmaline	8	8	8	8	8	8	8
	Staurolite	5	5	4	2	4	4	4
	Epidote	4	4	4	4	4	4	4
	Chlorite	—	—	—	—	—	—	—
	Biotite	4	1	2	1	—	—	1
Heavy Residue: Non-Magnetic. S.G. $>$ 2·82.	Leucoxene	7	7	7	5	8	6	7
	Zircon	9	9	9	5	4	8	9
	Kyanite	5	4	5	6	6	3	5
	Anatase	1	—	—	—	1	—	1
	Rutile	7	6	6	4	6	4	6
	Brookite	—	1	—	—	—	?	1
	Topaz	5	4	4	4	3	3	4
	Andalusite	5	5	5	5	6	7	5
	Muscovite	5	5	4	4	4	4	4
	Corundum	—	—	—	—	—	—	—
	Cassiterite	4	4	?	—	—	—	4
	Xenotime	?	—	—	—	—	—	?

A. Yellowish-brown sand, 6 feet below the surface. Average of several samples taken laterally, including one from the Cornish Sand Company's pit.

B. White sand, 8 feet below the surface, Cornish Sand Company's pit.

C. Brown sand, 14 feet below the surface, Cornish Sand Company's pit.

D. Reddish-brown sand and grit, 20 feet below the surface, Cornish Sand Company's pit.

E. Chocolate moulding sand, 22 feet below the surface, Cornish Sand Company's pit.

F. Reddish-brown sand, 23 feet below the surface, bottom of the pit, Cornish Sand Company's pit.

G. Average composition of the St. Erth sands.

[Conventional signs as in the previous table, p. 357.]

A quantitative estimation of the mineralogical composition of an average sample of St. Erth sand gave the following results:—

Quartz, 91·6 per cent.
Authigenous and other 'light' material, 8·26 per cent.
Magnetic residue, 0·120 per cent.
Non-magnetic residue, 0·025 per cent.

From this it will be seen that the relative proportion of the magnetic to the non-magnetic residue is less, and the percentage of authigenous matter (chiefly limonite) greater than in the case of the St. Agnes deposits. The principal mineralogical features of the St. Erth sands consist in the abundance of tourmaline (variable in colour, size, and shape), in the marked 'flooding' of well-rounded zircon-crystals at the upper horizons, in the rare appearance of garnet (absent both at St. Agnes and St. Keverne), in the presence of staurolite in variable quantity throughout, and in the occurrence of the same type of kyanite (fig. 2, p. 371) as that remarked at St. Agnes, though generally less common here than at that locality. Quartz, muscovite, magnetite, ilmenite, kyanite, and cassiterite all present characteristics similar to the species occurring at St. Agnes (p. 358), and need not be further mentioned. The following minerals, however, are specially to be noted:—

Garnet.—This mineral, although very rare, is distributed laterally throughout the upper yellowish-brown sand, and also vertically through the upper facies of the deposits. It occurs as subangular grains never longer than 0·2 mm., with a refractive index of about 1·76, pink in colour, and traversed by numerous intersecting cracks. Its isotropic character is consistent.

Tourmaline.—This most abundant mineral is present both as large and as small grains and prisms, the prisms averaging about 0·3 mm. and the grains 0·25 mm. in length. The colours range from grey, blue, purple, green, brown, to yellow, and in many cases parti-coloured grains are seen. A noteworthy feature of the species is its occurrence as basal sections yielding good uniaxial interference-figures; such basal grains are extraordinarily common at all horizons, and are indistinguishable from similar grains noticed in the St. Agnes deposits (p. 358). Extreme rounding, subangularity, and irregular outline of grains are all developed, the last-mentioned feature being especially noticeable in the reddish-brown sand near the base of the series.

Staurolite.—Common in the upper beds, but scarcer at the lower horizons, this mineral is well individualized at St. Erth. It occurs as rounded brownish-yellow grains, exhibiting weak pleochroism, high refractive index and, in some instances, biaxial interference-figures. The average grains measure 0·2 mm.

Epidote.—Grains of this mineral, when present, are all very similar. They present sharply angular outlines, clear greenish-yellow coloration in transmitted white light, a refractive index equal to that of the garnets, and weak pleochroism. Between crossed nicols, third-order birefringence colours (chiefly blues and yellows) are exhibited, and many of the grains show typical partial interference-figures for cleavage-flakes parallel to (100).

Zircon.—Reference has already been made above to the 'flooding' of this mineral at certain horizons, which is its most characteristic feature. Compared with the other minerals associated with it, and also with the similar species occurring at St. Agnes, the St. Erth type is much smaller, and much more rounded; the average size is 0·1 mm.

Rutile.—In contrast to the St. Agnes deposits, this mineral occurs very commonly at St. Erth; the prevalent type of grain is a well-rounded, dusky reddish-brown prism, with faint pleochroism and a very high refractive index. Sharply angular and irregular fragments of clear yellow rutile also occur, especially in the uppermost yellowish-brown sands.

Brookite.—Only one grain of this mineral was identified in the samples examined, and this occurred in the white sand associated with rutile, as an irregular, well-rounded, yellow crystal flattened parallel to (100) and striated parallel to the vertical axis. The grain is feebly pleochroic, possesses a very high refractive index and birefringence, and exhibits a well-defined biaxial positive interference-figure.

Topaz.—This mineral is commoner in the upper horizons than in the lower, and in some cases occurs in excess of the andalusite. The grains are usually somewhat irregular, but are clear, colourless, void of inclusions, and average from 0·2 to 0·3 mm. in diameter.

Andalusite.—The chief feature of this species, as occurring here, is the intense blood-red pleochroism exhibited by nearly all the crystals, which are in this, and in all other respects, similar to those of St. Agnes.

(*c*) St. Keverne.

Microscopical examination of the Crousa-Common deposits gave the following results :—

	Horizon	A.	B.	C.	D.
Light Material: S.G. $<2·82$.	Minerals.				
	Quartz	Essential constituent throughout.			
	Muscovite	5	5	5	5
	Glauconite	3	2	3	2
	Ferruginous cement	Essential authigenous material.			
Heavy Residue: Magnetic. S.G. $>2·82$.	Magnetite	7	7	7	7
	Ilmenite	8	8	8	8
	Garnet	—	—	—	—
	Tourmaline	8	8	8	8
	Staurolite	1	1	1	1
	Epidote	4	4	4	4
	Chlorite	1	1	1	1
	Biotite	2	1	1	1
Heavy Residue: Non-Magnetic. S.G. $>2·82$.	Leucoxene	7	7	8	7
	Zircon	4	4	5	4
	Kyanite	—	—	—	—
	Anatase	5	5	8	5
	Rutile	4	4	5	4
	Brookite	—	—	2	2
	Topaz	4	5	5	5
	Andalusite	8	9	9	9
	Muscovite	5	5	7	5
	Corundum	—	—	—	—
	Cassiterite	4	4	1	4
	Xenotime	—	—	—	—

A. 'Gravel' from Crousa Common, St. Keverne. (Average of several samples.)
B. 'Gravel' from a quarry by the main road, 9th milestone from Helston, St. Keverne.
C. 'Gravel' from the base of the deposits, same locality as B.
D. Average composition of the St. Keverne deposits.

[Conventional signs as in the previous tables.]

The mixed, unsorted character of these Crousa-Common deposits renders quantitative data of little direct value in this case. Mention has already been made of the variation in grade-size shown by the constituent particles, and the general coarse texture of the sands has been commented upon; such variations are reflected in the elutriation-curve for these sediments plotted by Prof. P. G. H. Boswell, which compares very unfavourably with the curve of the St. Erth facies.[1] It would be expected that the coarser the sample is in the aggregate, the less will be the yield of heavy residue, and this was found to be the case in the present instance. The samples collected varied considerably in average texture, and the residues fluctuated quantitatively from 0·01 to 0·2 per cent. The only uniform feature was the mineralogical composition of the sediments, which was found to be constant qualitatively throughout. The characteristic minerals, both in frequency of occurrence and in optical properties, are undoubtedly ilmenite, anatase, and andalusite; the last-mentioned species particularly predominates in some samples, and in one non-magnetic residue, save for three grains of anatase, it constituted the entire crop. The negative characteristics that should be noted are the extreme rarity of staurolite, the entire absence of kyanite and garnet, and the dropping-off of zircon, when these minerals are considered with reference to the other deposits.

Ilmenite.—The contrast between this mineral and the magnetite tends to be most marked in these deposits; whereas the latter frequently occurs in well-recognizable octahedra, the former is invariably irregular, fragmental, and ragged. In some cases the partial alteration to leucoxene can be seen, and secondary outgrowths of tiny ultra-microscopic crystals (probably of rutile or anatase) from the opaque nucleus are by no means uncommon.

Tourmaline.—This species is again remarkable for the abundance of basal grains, as at St. Agnes and St. Erth. Prismatic crystals are present, but less frequently than at those localities. The prevalent type is usually rounded but subangular, and many grains show a marked fracturing. The average grain measures 0·4 mm. in diameter.

Anatase.—This species is undoubtedly the distinctive feature of these deposits, and in no other sediment known to me are the crystals so abundant, so beautifully formed and preserved, and so conspicuous as they are here. The common type is tabular parallel to (001), either as individual crystals or as composite groups of tabular forms in parallel growth. The colour is invariably indigo-blue or greyish-blue; refractive index extremely high; birefringence high, but tending to be masked by the natural colour; interference-figure (uniaxial negative) remarkably clear. These crystals average about 0·25 mm. in longest diameter. Occasionally fractured grains occur which are almost opaque in white light, but easily studied and identified with convergent light.

Andalusite.—On the whole, grains of this mineral assume much larger dimensions here than in former instances. They are rarely well crystallized, but tend to occur as rudely triangular fragments, fractured, with 'pitted' surfaces, and often crowded with inclusions. The blood-red pleochroism is

[1] 'British Resources of Sands & Rocks used in Glass-making' 2nd ed. (1918) pp. 30, 31.

shown by many individuals, but several of the grains are bereft of this property, particularly the clearer and more irregular types. The refractive index and birefringence are normal, and a few grains exhibit biaxial negative interference-figures. The average diameter of the grains is 0·5 mm., and frequently natural grading factors have produced local concentrates composed of individuals almost without exception conforming to this dimension. In both physical and optical characters, this andalusite differs in no fundamental respects from that found in the more northern localities.

The other minerals present call for no special remark, save possibly the brookite, of which two grains were identified in the samples taken from the base of the deposits. These grains exhibited characteristics similar to those possessed by the same mineral noted in the St. Erth Beds.

VI. Comparison and Correlation of the Deposits.

Average mineralogical composition.			
Species.	St. Agnes.	St. Erth.	St. Keverne.
Magnetite	7	7	7
Ilmenite	5	5	8
Garnet	—	1	—
Tourmaline	8	8	8
Staurolite	3	4	1
Epidote	4	4	4
Chlorite	2	—	1
Biotite	2	1	1
Leucoxene	7	7	7
Zircon	5	9	4
Kyanite	6	5	—
Anatase	2	1	5
Rutile	2	6	4
Brookite	—	1	2
Topaz	5	4	5
Andalusite	7	5	9
Muscovite	5	4	5
Corundum	?	—	—
Cassiterite	1	4	4
Xenotime	? 1	?	—

[Conventional signs as in the previous tables.]

If we compare the average mineralogical composition (heavy residues) of the St. Agnes, St. Erth, and St. Keverne deposits, taking also into account the crystallographical, physical, and optical properties of the component species, it soon becomes abundantly clear that, although we are dealing with isolated outcrops, the deposits all present marked petrographical affinities suggesting a close genetical relationship. Reviewing the results of the investigation from the purely mineralogical standpoint, and in order to validate subsequent questions of correlation and source of origin of material, we have to enquire into the cumulative evidence furnished by the more important mineral species, especially with regard to their frequency or infrequency of occurrence, their persistence in each locality, and the constancy of their mineralogical properties as an indication of consanguinity of origin.

(i) Frequency of Occurrence (deduced from the average mineralogical composition of each deposit).

Abundant. Magnetite, tourmaline, leucoxene, andalusite.
Common. Ilmenite, zircon, topaz, muscovite, kyanite.
Scarce. Epidote, rutile, cassiterite, staurolite, anatase.
Rare. Garnet, chlorite, biotite, brookite.
Doubtful. Corundum, xenotime.

(ii) Persistence of Species: (Distribution Diagram).

Mineral.	St Agnes.	St. Erth.	St. Keverne.
Magnetite	——	——	——
Ilmenite	——	——	——
Garnet		——	
Tourmaline	——	——	——
Staurolite	——	——	——
Epidote	——	——	——
Chlorite	——		——
Biotite	——	——	——
Leucoxene	——	——	——
Zircon	——	——	——
Kyanite	——	——	
Anatase	——	——	——
Rutile	——	——	——
Brookite		——	——
Topaz	——	——	——
Andalusite	——	——	——
Muscovite	——	——	——
Corundum	?		
Cassiterite	——	——	——
Xenotime	?		

(iii) Constant Mineralogical Features noted throughout.

Magnetite. Rounded octahedra or grains. Not ragged.

Ilmenite. Commonly irregular and ragged.

Tourmaline. Prismatic and rounded grains both present. Deep-brown basal sections with interference-figures very common. Numerous and parti-coloured grains occur in all cases.

Staurolite. Well-worn grains with similar physical and optical properties noted throughout.

Epidote. Always sharply angular, greenish-yellow in colour, many grains exhibiting partial interference-figures. Weak but characteristic pleochroism.

Zircon. Extremely well-rounded prismatic forms characteristic in all cases. A few of the 'stumpy' prismatic varieties always present.

Kyanite. Precisely the same type present in both the St. Agnes and the St. Erth deposits. The rounded, elongated prisms, showing traces of a well-marked (010) cleavage, are always present.

Anatase. Commonly in indigo-blue tabular crystals, seldom abraded.

Rutile. Well-rounded 'foxy'-red or reddish-brown, feebly-pleochroic grains are the prevalent type, with a subordinate amount of yellow translucent fragments.

Topaz.	Invariably clear, colourless and transparent, and in irregular flakes.
Andalusite.	Well individualized as regards optical properties, particularly that of pleochroism, which is intense in many grains. Often well crystallized, although usually turbid with alteration-products such as kaolin; contrasting strongly with topaz in these respects.

The foregoing species have been selected on account of their importance quantitatively, and on account of their value for purposes of correlation.

The marked similarity of the mineralogical composition of the sediments and of the more precise physical and optical characters of the component species, can only be explained on the assumption of derivation from a homogeneous 'distributive province,' using the phrase to include both igneous and sedimentary facies.[1] Quite apart from general lithological resemblance and similar mode of occurrence of the deposits, we find that (excepting two doubtful minerals), in only four cases are species non-persistent throughout, and of these all save one (kyanite) are comparatively unimportant. Such uniformity in composition is most significant, and is particularly striking in the present case. Again, the frequency of occurrence of the important species, and the similarity of crystallographical and optical properties, and of the nature and degree of abrasion exhibited by these species, are factors which we cannot overlook, and are strongly suggestive of the truth of the hypothesis above postulated. It would seem not unreasonable, then, to conclude that the deposits were the product of a definite period of erosion, subsequent denudation, probably marine, determining the removal of much of the detritus which had accumulated; the survival of a few isolated remnants of the original mass was by no means fortuitous, but due entirely to favourable conditions of deposition. On this basis, the initial assumption of contemporaneity of the deposits under discussion becomes a distinct probability, and receives support not only from the mineralogical evidence cited above, but also from topographical criteria to be discussed in the sequel.

VII. Source of Origin of the Deposits.

Any well-differentiated phase of detrital deposition must of necessity give rise to sediments reflecting the nature and composition of the parent rocks of the comminuted material; it follows, therefore, that an enquiry into the normal petrological habitat of the several mineral species concerned should furnish us with valuable evidence as to the source of origin of the deposits, which, when combined with the geological and physiographical knowledge obtainable from the area to-day, should serve as a foundation for a geographical reconstruction of this part of Britain at the epoch under consideration. The results of such an enquiry show that

[1] The term 'distributive province' was suggested by Mr. A. Brammall, M.Sc.

with the exception of two or possibly three of the mineral species characterizing these deposits, all occur in rocks known to-day in the vicinity of the outcrops under consideration: in other words, 85 per cent. of the species are probably of local origin. With regard to xenotime, this mineral has not been recorded from the acid igneous rocks of Cornwall, so far as I am aware; but there is no reason why it should not be present in some of the granite-masses, even though sparsely distributed. Staurolite is essentially an 'Armorican' mineral, with a type-locality in Britanny to-day: its origin may be more pertinently discussed hereafter (p. 370). The kyanite is probably in the nature of a remanié mineral, and its crystallographic features point to derivation from a pre-existing sediment, such as the Lower Greensand; the nearest outcrop of the Lower Greensand, containing kyanite similar to that of St. Agnes and St. Erth, is in the north-west of Wiltshire: the significance of this fact will be ultimately apparent.

The cumulative evidence to be obtained from a study of these minerals shows them to have belonged originally to a distributive province which included acid, basic, and ultrabasic rock-types, with an associated suite of metamorphic rocks: such a province clearly is only indicative of Cornwall itself where all such rock-facies are known to occur. Excluding, then, the staurolite and kyanite, the origin of which is discussed hereafter, the mainly local derivation of the deposits under investigation would seem to be most decidedly indicated.

VIII. Pliocene Geography of the South-West of England.

One of the most difficult problems facing the geologist in Western Cornwall is the adequate explanation of certain outstanding physical features, for which there is but little direct geological evidence; among such features that of the St. Erth valley (see map, fig. 1, p. 350) is probably the most striking, and a close investigation of its nature and origin is a *sine quâ non* in any intelligent discussion of Pliocene palæogeography.

The late Clement Reid, in a paper 'On the Probable Occurrence of an Eocene Outlier off the Cornish Coast,'[1] drew attention to this valley, and interpreted its origin in the light of his theory of the existence of Eocene gravels on the floor of Mounts Bay. He inclined to the view that the St. Erth valley was the site of an old Eocene river flowing probably from north to south through this valley, the river being responsible for the transportation and accumulation of the material in the bay. Thence the inference is that the initiation of this valley was the product of early Eocene erosion, the material, composed of 86 per cent. of Chalk flint and 2 per cent. of Greensand chert, being derived from Cretaceous rocks, presumably from the north-east. That the valley was not originally formed in Pliocene times is apparent from careful

[1] Q. J. G. S. vol. lx (1904) p. 113.

observation to-day; the mode of occurrence and the elevation of the St. Erth deposits at 170 feet above sea-level both tend to suggest a greater antiquity, and hence a probable Eocene age. On this assumption, the belief is justified that the whole of South-Western Cornwall, if not the greater part of the South-West of England, stood then at a higher level than it does now, and the forces of denudation probably continued to act unchecked throughout Oligocene and early Miocene times, and possibly later. Such a belief can only be based on analogy with contiguous areas to the east, since in Cornwall itself we have really no direct evidence of the trend of geological events between Upper Palæozoic and Pliocene times—an enormous gap in the stratigraphical record.

With the renewal of folding along the ancient Armorican lines in Miocene times, the effects of which are so marked in the Isle of Wight and the Isle of Purbeck, it is possible that considerable changes were wrought in the surface-relief of Southern Cornwall, although it is by no means certain that these tectonic influences extended so far westwards; if they did, it would be expected that the tendency was towards the production of asymmetrical fold-features with a gentler dip southwards, as is the case in these localities, though of far less severity in the west where the movements were decreasing in intensity. In Cornwall the effect of such deformation would probably only be an accentuation of the chief Palæogene physical features, and such drainage-courses as the St. Erth valley with its southerly gradient would receive an increased impetus in the work of discharging material into the English Channel. Even if the original early Tertiary drainage of the St. Erth valley were in the opposite direction: that is, from south to north (which is extremely unlikely from all that we can gather of its history), the result of Miocene earth-movement would still tend to produce drainage into the English Channel in South-Western Cornwall, and at the close of Miocene times the St. Erth valley would in any case be well differentiated. Whatever happened during this pre-Pliocene period, two factors stand out very clearly from the late Miocene records: namely, the general subsidence of the area in early Pliocene times and the concomitant accentuation of the '400-foot platform' as a result of marine erosion.[1] This Pliocene platform is one of the most characteristic physical features of Cornwall, and it can be traced at heights varying from 370 to 420 feet above O.D., at intervals along both the southern and the northern coasts of the county, extending from the coastal margin well inland to the higher Palæozoic country which constituted the ancient Pliocene land-area (shown in the accompanying sketch-map, fig. 1, p. 350). It is difficult to estimate the precise amount of this subsidence from the data at present available; but, taking into account the St. Erth deposits, the character of their fauna, their lithology, and present topographical evidence, Clement

[1] See Mem. Geol. Surv. Sheets 351, 358, 346, 359, and H. Dewey, Q. J. G. S. vol. lxxii (1916–17) p. 63.

Reid's estimate of 340 feet is probably under rather than over the actual amount, particularly when the St. Agnes and St. Keverne deposits are also considered.[1] The difference in topographic level of the St. Erth deposits compared with those of the other localities can only be due to the former having been laid down in a pre-existing hollow which, as subsidence progressed, became ultimately modified by the sculpturing of the '400-foot' feature: this implies deposition of the St. Erth material in deeper water than in the case of the other deposits, a belief justified both on palæontological and on petrographical grounds, and by comparison with the markedly shallow-water character of the St. Agnes and especially the St. Keverne facies. Thus the St. Erth valley, from its initiation as an early Tertiary river-course, became transformed at the close of Miocene times into a strait separating the Land's End area from that of the main Cornish land-mass; and it is noteworthy that, even with the present configuration of the land, a subsidence of only about 150 feet would be required to re-establish such conditions. With a subsidence of 364 feet, as above postulated, the geography of Western Cornwall assumes widely different aspects, the peninsula becoming in fact a series of large and small islands, a miniature West Indies.

Under such conditions of submergence the present nature and disposition of the Pliocene sediments is readily understood: at St. Agnes, the Beacon, rising to a height of 628 feet, becomes part of a large island, the northern and leeward shoreline of which formed the upper limit of the submarine shelf upon which the deposits were laid down. In the vicinity of St. Erth and Lelant, much larger islands existed on the west and on the east, the former comprising the Land's End granite and metamorphic area, the latter comprising the petrographically similar uplands of Carn Brea, Carn Menellis, and the Godolphin Hills. At St. Keverne, the Carn-Menellis mass is again the dominant background feature, and the gently sloping Lizard platform on the south becomes the locus of deposition of a mass of sand and gravel thence derived, a remnant of which has survived late Tertiary erosion and is preserved in the form of the present outcrop on Crousa Common. Then, as regards the Polcrebo deposits, in my opinion their occurrence at a height of 480 feet above O.D. can only with extreme difficulty be reconciled to this phase of geological history: if, in the absence of all other evidence, they are to be regarded as having been formed collaterally with the Pliocene deposits, how can we explain their present anomalous position above sea-level, and the absence of any like feature, either lithological or topographical, elsewhere in the county? Their general character would seem to fit in far more reasonably with Quaternary erosion than with any older period of denudation.

Hence, reviewing the chief features of these deposits of South-Western Cornwall in the light of the foregoing topographical data,

[1] 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 65.

it is not difficult to understand the similarity of composition of their constituent minerals, their predominantly local derivation, the physical features of the grains (particularly quartz) as connoting the abrasive action of sea-water, and the indication of the deeper-water character of the St. Erth facies when compared with that of the other localities.

Lastly, the sources of origin of both the staurolite and the kyanite as 'foreign' minerals, and their bearing on the wider problem here discussed, have to be considered. In the case of the staurolite, the most probable source of derivation would seem to be from the south, from a land-mass, though now submerged, having geological and tectonic connexion with Britanny and the North-West of France, where we know this mineral to occur in quantity. The researches of Dr. H. H. Thomas[1] have shown that the staurolite in the Bunter deposits of Devon and Somerset probably had this origin, in view of the fact that the Armorican massif is generally considered to have extended much farther north-westward at the close of Upper Palæozoic times; although it was afterwards largely submerged, particularly in the late Cretaceous Period, renewed folding and uplift in Miocene times, involving the South of England and the North-West of France, determined the reappearance of this Armorican continent in the area now occupied by the English Channel, and the concomitant westward recession of the sea. The effect of this uplift would be to promote drainage both from Southern England and from the Armorican continent into a broad central river flowing westwards along the basin of the English Channel, and probably emptying itself into the sea at a point some miles south of the present Cornish coast. The action of marine currents bordering the western shore-line of this uplifted area would tend to the lateral distribution of the detritus brought down, although with a strong inclination to a northerly direction, owing to the probable south-westerly on-shore wind prevailing from the open ocean, as is the case at the present time. The comparative rarity of staurolite in the deposits, however, suggests a gradual alteration in potency and direction of these marine currents, such as would be occasioned by subsidence of the land-areas and the advance of the sea eastwards up the Channel once more; such factors reflect the initial conditions caused by the early Pliocene submergence to which reference has already been made.

In the case of kyanite, the evidence is much more obscure, though derivation from the north-east is suggested on petrographical grounds. Attention has already been called to the marked similarity between the Pliocene kyanites and those commonly occurring in the Lower Greensand; in order to test this point further, it became advisable to examine the non-magnetic residues from the Lower Greensand in the vicinity of Seend (Wiltshire), some 4 miles west of Devizes. Accordingly, such an investigation

[1] Q. J. G. S. vol. lviii (1902) p. 630.

was made, and with entirely satisfactory results. In figs. 2–4 from drawings of species occurring in St. Erth, St. Agnes, and North-Western Wiltshire, it will be seen that there is a marked similarity in crystal form in all cases; this is supplemented by a careful comparison of all the kyanite-grains in the Seend residue with those in the Cornish deposits. On the whole, the Pliocene grains are more worn and rounded than those of the Lower Greensand, as we should expect; but the species from Seend show the

Fig. 2.—*Kyanite from Pliocene, St. Erth* (×70).

Fig. 3.—*Kyanite from Pliocene, St. Agnes* (×70).

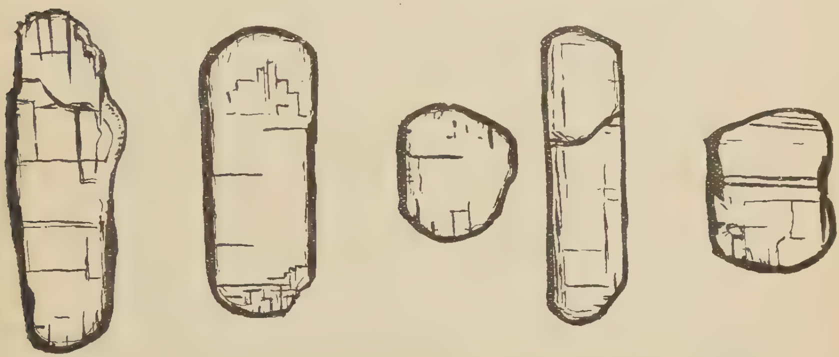
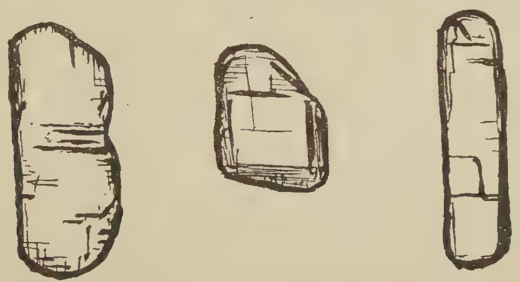


Fig. 4.—*Kyanite from Aptian, Seend, Wiltshire* (×70).



same characteristic prisms terminated by (001) or basal parting, further individualized by cleavage-traces parallel to (010) and (001), as well as the short 'stumpy' varieties met with in the Pliocene deposits. This mineralogical similarity seems, at first, to be but slender evidence on which to found a source of origin for the kyanite occurring in the Cornish deposits; but, when certain other factors are taken into account, it soon becomes apparent that this north-eastern region was indeed the most probable source of supply.

The evidence of the existence of an ancient Eocene drainage from north to south has already been mentioned; as a matter of fact, the occurrence of scattered Chalk flints is by no means uncommon in Cornwall, as, for example, at Newquay[1] and Padstow,[2] where in the latter locality it is associated with Greensand chert as at Ludgvan,[3] the area examined by Clement Reid. The significance of this association of chert and flint is too strong to be ignored; clearly it suggests derivation from the east or north-east, where the typical developments of Cretaceous strata are known to occur. If we bear in mind the probably greater westward extent of such strata prior to early Tertiary erosion, it would seem not unreasonable to conclude that this material was carried south-westwards by an ancient river-system draining approximately along the line of the present Bristol Channel, receiving affluents possibly from South Wales on its northern bank and from Exmoor Forest and the northern part of Dartmoor on its southern bank, and finally emptying itself into the English Channel by way of the St. Erth valley. Such a drainage would be quite compatible with the little knowledge that we possess of the physiography of the South-West of England in the Palæogene epoch, before the renewal of folding in Miocene times. There is little evidence to show that this folding entirely obliterated any western drainage previously existing; on the contrary, such a trend was accentuated rather than opposed, for a north-and-south watershed was probably well established west of the Cotswold Hills in early Tertiary times, differentiating a main east-and-west drainage, the former into the Thames basin, the latter into the Bristol-Channel and Exmoor region, although the precise location of this watershed is at present obscure in so far as our information goes.[4] Miocene folding merely cut short the southward extension of that watershed by the superposition of an east-and-west line of flexures, now indicated by such tectonic features as the Kingsclere, Pewsey, and Mendip uplifts. Consequently, the ancestral drainage of rivers draining westwards, far from being obliterated, was resculptured to form the basis of the present river-system in this region, and material continued to be borne westwards until the Pliocene submergence set in. With this submergence came the gradual advance of the sea over the Miocene land-areas of the South-West of England, the drowning of pre-existing lowland topography, and the limitation of the distributive power of the sediment-bearing rivers. If the apportionment of the kyanite-grains in the Pliocene deposits is any criterion of these fundamental physiographical changes, then we can readily appreciate the absence of the species at St. Keverne,

[1] Mem. Geol. Surv. Sheet 346 (1906) p. 65.

[2] *Ibid.* Sheets 335 & 336 (1910) p. 93.

[3] *Ibid.* Sheets 351 & 358 (1907) p. 68.

[4] Some light was thrown on this problem recently by Mr. W. D. Varney at a meeting of the Geologists' Association on May 6th, 1921, when a paper on the 'Geological History of the Pewsey Vale' was read (Proc. Geol. Assoc. vol. xxxii, p. 189).

its appearance at St. Erth, and its still commoner occurrence at St. Agnes. St. Keverne being the southernmost and St. Agnes the northernmost locality. The probable trend of advance of the Pliocene sea was from south-west to north-east, and obviously as this sea deepened, a constantly diminishing amount of material would find its way from the north-east to the submerged parts of Cornwall, and the influence of the drainage would be progressively curtailed. Again, the occurrence of staurolite at St. Agnes would seem to suggest the influence of south-westerly marine currents at least as far north as that locality, which further explains the absence of kyanite in the extreme south.

Finally, the possibility of derivation of the kyanite from any pre-existing Eocene deposits in South-Western Cornwall is negatived by the entire absence of Chalk flints and Greensand cherts from the Pliocene deposits, indicating the extensive erosion that the older deposits suffered in early and Middle Tertiary times.

IX. Summary and Conclusions.

The results of the investigation may now be summarized as follows:—

(1) The petrographical characters of the St. Agnes, St. Erth, and St. Keverne deposits have been shown to be substantially the same, and they suggest derivation from rocks belonging to a homogeneous 'distributive province' such as would be furnished by the Palæozoic rocks of Cornwall.

(2) The geological age of the St. Erth Beds has previously been proved palæontologically to be early Pliocene. Although no fossils occur in the St. Agnes or St. Keverne deposits, and since the latter are the products of contemporaneous erosion, by petrographical correlation their Pliocene age is established.

(3) In the case of the alleged occurrences of Pliocene material at Canons Town and Polcrebo, in neither instance is the evidence sufficient to establish relationship with the other deposits, although there is little doubt that, if an outcrop exists at the former locality, it has a direct connexion with the St. Erth material on the opposite side of the valley. The Polcrebo gravels are, in my opinion, the product of much later erosion.

(4) The topographical evidence furnished by the '400-foot' plateau has been used, in conjunction with the petrographical investigation of the deposits associated with it, as a means of reconstructing the early Pliocene geography of Cornwall. The occurrence and distribution of the two species, staurolite and kyanite, have been shown to be of specific value in this connexion, the former as connoting the existence of the ancient Armorican land-mass, the latter as indicating the direction of drainage from the north-east, at the close of Miocene and the commencement of Pliocene times.

In conclusion, it is hoped that the methods employed and the results obtained from this investigation will indicate a possible solution in other cases where palæontological evidence is scanty or wanting; used cautiously and over limited areas, such petrographic methods should prove invaluable to the stratigrapher.

It remains for me to record my thanks to Prof. W. W. Watts, Dr. H. H. Thomas, and Prof. P. G. H. Boswell for their kind help during the course of this work. Mr. G. M. Part very kindly reproduced the kyanite-grains shown in figs. 2–4, and I am also indebted to Mr. G. S. Sweeting for the assistance which he has rendered during the preparation of the manuscript.

Discussion.

Prof. P. G. H. Boswell welcomed the paper as a contribution to our knowledge of the petrology of the Tertiary deposits of the West of England. The Author's records of the characteristic minerals were confirmed by the speaker's own identifications. It was a noteworthy but unexplained fact that, while the Permian, Trias, Lias, and Inferior Oolite of the West of England were characterized by an abundance of garnet, that mineral was absent from, or extremely rare in, the Cretaceous, Eocene, Oligocene, and Pliocene of Devon and Cornwall, although it was a common constituent of the Palæozoic rocks of Devon, Cornwall, and Britanny.

He enquired why the Author desired to have the staurolite in the St. Keverne sands derived from the old 'Armorican' land on the south-west, unaccompanied by its usual associate, kyanite; while, in the case of the sands at St. Agnes and St. Erth, he assumed a Lower Greensand origin in the north-east for the same two minerals. The absence of kyanite at St. Keverne seemed to be inconclusive in the matter of the derivation of the material.

The paper was valuable for the additional light which it threw upon early Pliocene geography. The Author's conclusions, although novel, were not necessarily inconsistent with our ideas of the distribution of Pliocene land obtained from a study of the fauna of the St. Erth clays and the Crags. That the migration of southern species into the North-Sea basin over what is now the English Channel and Kent was possible in early Pliocene times, but was prevented during the deposition of the Middle and Upper Pliocene, presumably by the raising of a land or shallow-water barrier, is indicated by the molluscan faunas. Further, the totally different character of the mineral assemblages of the Cornish and East Anglian Pliocene (the latter having apparently been derived from the south-east) supports the view. Moreover, the similarity in certain mineralogical respects (notably in the rarity of garnets) of the Lenham Beds and the Cornish Pliocene may prove to be more than mere coincidence.

Mr. G. M. Part said that he had hoped that this paper might suggest some reasonable source for the very similar assemblage of minerals found in some of the Glacial drifts of Pembrokeshire, which it could only be surmised were derived from some similar Tertiary deposit. As the Pembrokeshire drifts were derived from a westerly or north-westerly direction, this would involve a northern drainage, if Cornwall had provided any of the material for a deposit from which the blood-red pleochroic andalusite had found its way into the gravels.

Dr. H. H. Thomas agreed with the Author that the kyanite of these deposits was most probably derived from sediments of Cretaceous age. The absence of kyanite from the Western New Red rocks was strong evidence in support of the Author's view. He thought that the grains of staurolite with frayed-out cleavages owed this distinctive character to their derivation from large crystals: that was the conclusion to which he had come from a study of the abundant and large grains found in the Western Trias. With regard to the great similarity between the mineral assemblages of the Cornish Pliocene and the drift-sands of Pembrokeshire, he had many years ago suggested the latter's partial derivation from Tertiary deposits occupying, in Glacial times, a position in the bed of the Irish Sea.

Mr. G. Barrow was greatly interested in the Author's work, as it dealt with what are commonly known as Pliocene deposits, now occurring at heights much above sea-level. The Geologists' Association had taken a special interest in these high-level deposits, which occurred in patches extending from the south-east of Kent at least as far as the neighbourhood of the Guildford gap in the Chalk. Apart from the Lenham Beds, fragments of undoubtedly marine shells have been found in the gravels of Headley Heath. The mode of occurrence of these is important, as it suggests where to look for further casts. They occur only when the sand surrounding the original shell-fragments has been firmly cemented by iron-oxide, and nowhere else. The examination of the deposit on the ground suggests that these gravels are beach-deposits, with broken shell-fragments once common in them. All these fragments have been dissolved; but, where iron-oxide filtered in and cemented the sand before solution took place, casts of some fragments are preserved. It is in such cemented patches that we must in future look for evidence of the age and nature of these beds; this knowledge not only shows where to look, but where it is useless to look, and this so far covers more than 90 per cent. of the whole.

Mr. T. Crook said that it was particularly pleasing to note the emphasis laid on sampling. Failure to record a mineral in such deposits did not necessarily mean that the mineral was absent; but, with careful sampling, such as the Author appeared to have carried out, much better results were likely to be obtained than when records were made on specimens collected haphazard. It

seemed to the speaker that it would be very useful if the Author would include in his paper an account of the method of sampling adopted, so that other workers might be able to obtain results that were fairly comparative.

With regard to the mineral composition of the sediments described, it was perhaps worth while to enquire whether the relative amounts of such minerals as garnet, staurolite, and kyanite, which were all metamorphic minerals in the ordinary sense, and might have emanated from the same ultimate source, were in any way connected with differences in chemical stability. Such differences had a good chance of asserting themselves where the proximate derivation was from other sediments, and where consequently the minerals had suffered repeatedly from the action of processes incidental to detrital sedimentation, possibly under a wide range of climatic variation.

Dr. J. W. Evans thought it improbable that the relative level of land and sea changed to the same extent throughout the area concerned. He did not believe that material could have been transported from the north-east by coastal wave-action. On the northern coast of Devon and Cornwall it was the north-westerly winds that produced the most important transporting action, and the movement was from south-west to north-east, not *vice versa.* If the kyanite had travelled from the Lower Greensand of the neighbourhood of Devizes, it must have been by means of river-action, when the Bristol Channel was a tract of alluvium and Devon and Cornwall were at a relatively low level.

Mr. R. B. Newton declined on palæontological grounds to accept a Pliocene age for the St. Erth deposits. His own studies (see Journ. Conch. vol. xv, 1916) of the shells from those beds were all in favour of their Upper Miocene horizon, and as exactly the same facies was apparent among the Lenham mollusca, he was of opinion that the St. Erth and Lenham Beds were of contemporaneous origin. He mentioned the occurrence of similar species of shells in the Gourbesville deposits of Normandy which had been described by M. Gustave Dollfus (Bull. Soc. Géol. Normandie, 1880, and C. R. Assoc. Franç. Av. Sci., Cherbourg, 1906, pp. 358–70), and referred to the Redonian stage of the Miocene, which is considered the equivalent of the Upper Vindobonian horizon of Europe. The speaker was also of opinion that the palæontological evidence proved that the St. Erth as well as the Lenham deposits represented fragmentary remnants of the Continental Miocene development, which extended from Holland, Denmark, Northern Germany, and Northern France.

The Author, in reply to Prof. Boswell, said that it appeared to him unlikely that the staurolite could have come from the north-east, in view of the absence of kyanite from St. Keverne; if both the minerals had been derived from the north-east, kyanite should have penetrated at least as far as the staurolite, and it should appear with the latter at St. Keverne, which is actually not the

case. In reply to Mr. Part, the Author said that he had noticed the resemblance of the andalusite from the Glacial gravels of Pembrokeshire to the Pliocene species, but there was little doubt in his mind that the source of the Pembrokeshire deposits was from the west, possibly from an area now covered by the Irish Sea. In answer to Mr. Crook, the Author discussed the methods of sampling in the field at equal intervals along the strike of the deposits, and at each change of the lithological facies in vertical sections. The Author agreed with Dr. Evans that probably Cornwall stood at a higher level in early Tertiary times than it does at present; he specially drew attention, however, to the distinction necessary between the Tertiary deposits now occurring on either side of Dartmoor. In reply to Mr. Newton's criticism of the use of the word 'Pliocene' in connexion with these deposits, the Author said that this was essentially a palæontological aspect of the subject, and one which he did not feel competent to discuss; he had always been content to accept as a basis the admirable work of the late Mr. Clement Reid on the Pliocene Deposits of Britain.

13. JURASSIC CHRONOLOGY: II—PRELIMINARY STUDIES. *Certain* JURASSIC STRATA *near* EYPESMOUTH (DORSET); *the* JUNCTION-BED *of* WATTON CLIFF *and* ASSOCIATED ROCKS.

By S. S. BUCKMAN, F.G.S. (Read December 7th, 1921.)

CONTENTS.

I. INTRODUCTION.

THIS paper is to a certain extent a supplement to the communication on 'Certain Jurassic Strata of South Dorset' published by the Geological Society in 1910, in so far as it contains a study of another exposure of the Junction-Bed (Domerian, Whitbian, Yeovilian)[1] discovered farther east along the coast; but it also

[1] I, 5, pp. 61, 64, 82. These numerals in the footnotes throughout refer to the Bibliography, § VII, pp. 435–36.

gives a sketch of other Jurassic strata, the sequence of which should be of some importance in connexion with the chronology of the Oolite rocks.

About three-quarters of a mile east of Thorncombe Beacon[1] is Eypesmouth, a break in the cliffs where the little stream, the Eype (pronounced 'Eep,' to rhyme with sheep) runs into the sea. East of Eypesmouth is a lofty cliff of about a mile extending to West Bay—the harbour of Bridport.

The cliff is interesting geologically for three considerable faults: one, seen best about a quarter of a mile east of Eypesmouth is a fault of about 500 feet, bringing down Forest-Marble Beds to about the level of Yeovilian strata (*Dumortieria* hemera); another, about the same distance west of West Bay, brings down beds of Fullers' Earth almost vertically—it is a fault of about 120 feet; the third, immediately west of West Bay, shows Yeovilian strata of *Dumortieria* hemera or later—they are later than those on the west of the cliff—lying level with lower beds of Fuller's Earth: a drop as regards the latter of about 150 feet. So the middle and main portion of the cliff is let down by these faults. (See diagram 1, sketch-elevation of Watton Cliff, p. 383.)

The cliff faces about south-west by south and the faults run approximately west and east. The effect of the westerly fault is that destruction of the cliff has been hastened—there is a considerable recess from Eypesmouth to where the fault is now most visible, the cliff having been cleared back roughly along the line of fault, except for some more or less tumbled strata at its foot. The line of fault can be traced from what may be called 'the fault-corner' more or less towards Eypesmouth, where it disappears beneath the sand and shingle of the shore. This fault is shown on the 1-inch Geological Survey map, Sheet XVII, extending inland some 8 miles to the foot of the Chalk Downs—the Dorset Heights—near Long Bredy. It and the other faults run approximately parallel to, and are no doubt part of, the system of the Weymouth Anticline. A ground-plan of the cliff and the faults is appended (diagram 2, p. 384).

In the autumn of 1916 a large block lying on the platform of the fault-corner attracted my attention.[2] A portion that had been broken off exposed a weathered surface with *Thecidellæ*, and in some marl connected with them were unfamiliar ammonites in a fragmentary condition—Hildoceratids presenting almost the appearance of those which characterize the *discites*-beds of the Inferior Oolite. Further search showed specimens of *Tetrarhynchia thorncombiensis*, nom. nov.,[3] evidently derived.

Here was a case for investigation. The rock from which this block had fallen was subsequently located high up in the cliff-face, with also other tumbled blocks lying on a higher platform. Work

[1] I, 5, p. 59.
[2] This block has disappeared, buried perhaps by a slide of clay.
[3] See later, Palæontological Note, p. 435.

on these blocks showed that they were in the position of the Junction-Bed of Down Cliffs to Thorncombe Beacon, described in my former paper,[1] but that this exposure of the bed differed remarkably from what is found only about three-quarters of a mile away to the west. The Eype type consists mainly of strata with *Grammoceras striatulum* (*G. striatulum* sensu lato + *thouarsense* and other species)—a thin layer with these fossils was seldom present at the top of the Down Cliffs Junction-Bed; and here, at Eype, it is mainly a fine white lithographic stone, weathered faces of which show it to have been laid down as a fine white mud in paper-like layers: it is a very finely laminated bed. As I had, in my former paper, described at Burton Bradstock another white lithographic-stone bed, also associated with a fault and connected with Bridport Sands, the various interesting questions which arose will be readily understood.

Further work was done on this bed and the neighbouring strata during short holidays in the autumns of 1917, 1919, and 1920. A preliminary account of these investigations will, it is hoped, be equally interesting to the Society.

This paper was commenced on my return in 1917, but it was mainly written in the winters of 1918–19, 1919–20. During my visit to Eypesmouth in 1920, inspection of the bed showed that another investigator had taken details of it; a few days afterwards there came to Eypesmouth a letter from Mr. J. F. Jackson, enclosing a section. He kindly agreed to my suggestion that the account of his quite independent discovery and of his researches in the Junction-Bed of the western area should form an Appendix to this paper.[2] Therefore, I have divided this communication into two parts: the present paper, mainly concerned with these accounts of the Junction-Bed; and a proposed later paper, to give a fuller study of the main mass of Eype (Watton) Cliff—Fuller's Earth to Cornbrash—or the upper portion of the Lower Oolites.

II. Stratal and Faunal Details.

(A) Watton Cliff: the main mass.[3]

The following is a section of the beds exposed in Watton Cliff down to the '*margaritatus* bed,' showing the sequence, with

[1] I, 5, pp. 61, 64, 82.

[2] Mr. Jackson's account in his Section VIII does not seem to bear out my statement made above about *Grammoceras*; but then he might not feel sufficient confidence to identify *Grammoceras* by peripheries and cross-sections showing in a rock-mass. His Section IX would appear to deal with a block which I have not seen.

[3] The local name for the hill of which the cliff is the face is 'Fourfoot Hill' and for the cliff itself 'Clay Knapp.' E. C. H. Day has the name 'Fourfoot Hill' (III, p. 286). It may be suggested that the name is really 'Forefoot Hill,' from the tumbled platform at the base of part of the cliff, though this is to trespass dangerously near the usual error of folk-etymology. It seems advisable to distinguish it as Watton Cliff, from the name of the farm which lies behind it.

the position of the Junction-Bed. A consideration of the post Inferior-Oolite strata will be reserved for a later communication.

Section I—Watton Cliff, between Eypesmouth and West Bay (Bridport), Dorset.[1]

Beds 1–4 in the middle part of the Cliff.	*Sequence of Strata.*	*Thickness. (approximate) in feet*
1.	Forest Marble: massive shelly blocks with clay-partings	30
2.	Upper Grey Marls	30
3.	*a.* Micromorph *Ostrea* Bed: a mass of small oysters rarely 5 mm. long. Pedicle-valve of *Dictyothyris*; fragments of *Acanthothiris* (*A. bradfordiensis* Walker ?). *b.* The '*boueti*' or '*Rhynchonella* Bed': about 16 inches thick, mainly brown, crumbly, but white and compact for about 2 to 3 inches from the bottom. Full of specimens of *Goniorhynchia*,[2] often crushed; also occasional examples of *Ornithella* sp., crushed. Rarely *Terebratula langtonensis* Walker. *c.* Lower Grey Marl. *d.* White Marl.	5
4.	Large Conchoidal Bed: clays which break into large pieces. Measured up the cliff from 5 to 3 *d*	125
5.	*Ostrea-acuminata* Clays	20
6.	Brachiopod-Beds[3]: stone bands 6 to 12 inches thick separated by clays 18 to 30 inches thick. The contents of the stone-bands vary, and their sequence is somewhat supposititious *a.* *Ornithella* Bed. *b.* Large *smithii* Bed: *Rhynchonelloidea* aff. *smithii*, rather large examples without other brachiopods. *c.* *Acanthothiris* Bed: *A. powerstockensis*, *Rhynchonelloidea smithii*, and a large ammonite (*Parkinsonites* ?).[4] *d.* The *globata* Bed or *Terebratula* Bed: *Stiphrothyris* spp. = *Terebratula* cf. *tumida* Davidson (*T. globata* auctt. *non* Sow.) + *T.* cf. *nunneyensis* S. Buckman. *Rhynchonelloidea* cf. *smithii*. *e.* Shelly Bed: small forms of *Rhynchonelloidea* cf. *smithii*.	25

[1] See diagram 1, p. 383.

[2] For these and other brachiopod names see Bibliography, I, 6.

[3] Details of the Brachiopod-Beds were mostly obtained from blocks scattered on the beach during 1916. In 1917 and 1919 these blocks were nearly all buried; towards the end of my visit in 1920 a high tide removed shingle, disclosing the upturned edges of some stone-bands along the line of fault immediately east of Eypesmouth. These gave some help in the interpretation of the succession; but, owing to faulting and dislocation, they are not too reliable. A detailed section will be given in a later communication.

[4] Now in the Museum of the Geological Survey, Jermyn Street, London.

		Sequence of Strata.	*Thickness (approximate) in feet.*
	6*.	*Ostrea-knorri* Clays: possibly Bed 6 *e* is a layer in these	5
		The following beds (7–9) are to be seen in the eastern part of the cliff beyond the second fault:—	
	7.	Umber Bed: umber-coloured clays with a nodular band	20
	8.	Small Conchoidal Bed: clays with conchoidal fracture, breaking into small lumps	40
	9.	Ochre Band: a yellowish marly band about 1 foot thick, seen near the top of the cliff, eastern end, resting on	
		Laminated Clays: with light bands of somewhat calcareous rock. Occasional lumps of pyrites .	50
		Of the following beds, details for 10 and 11 are furnished by Burton Bradstock. There are Inferior Oolite rocks, the Black Rocks, just out to sea west of the third fault (see later, p. 430). Then part of No. 12 is seen immediately east of the third fault, and the basal part of No. 13 is found with succeeding beds in the cliff west of the first fault:	
	10.	Belemnite-Clays	15
Bajocian } Aalenian }	11.	Limestone-mass of the Inferior Oolite	16
Yeovilian	12.	Bridport Sands	130
	13.	Down-Cliff Clay	70
Whitbian	14.	Junction-Bed: fine creamy-white lithographic stone in paper-like laminæ (*Grammoceras* of *striatulum-thouarsense* types) and yellowish conglomerate, somewhat sandy, with derived *Tetrarhynchia thorncombiensis*. For detailed section, see later, p. 387	5
Domerian	15.	Thorncombe Sands[1]: yellow sands with doggers	35
	16.	Blue clay[2]	2
	17.	*Margaritatus* Bed: a prominent and easily recognized datum-line	1
	18.	Down-Cliff Sands.[3]	
		Approximate total	624

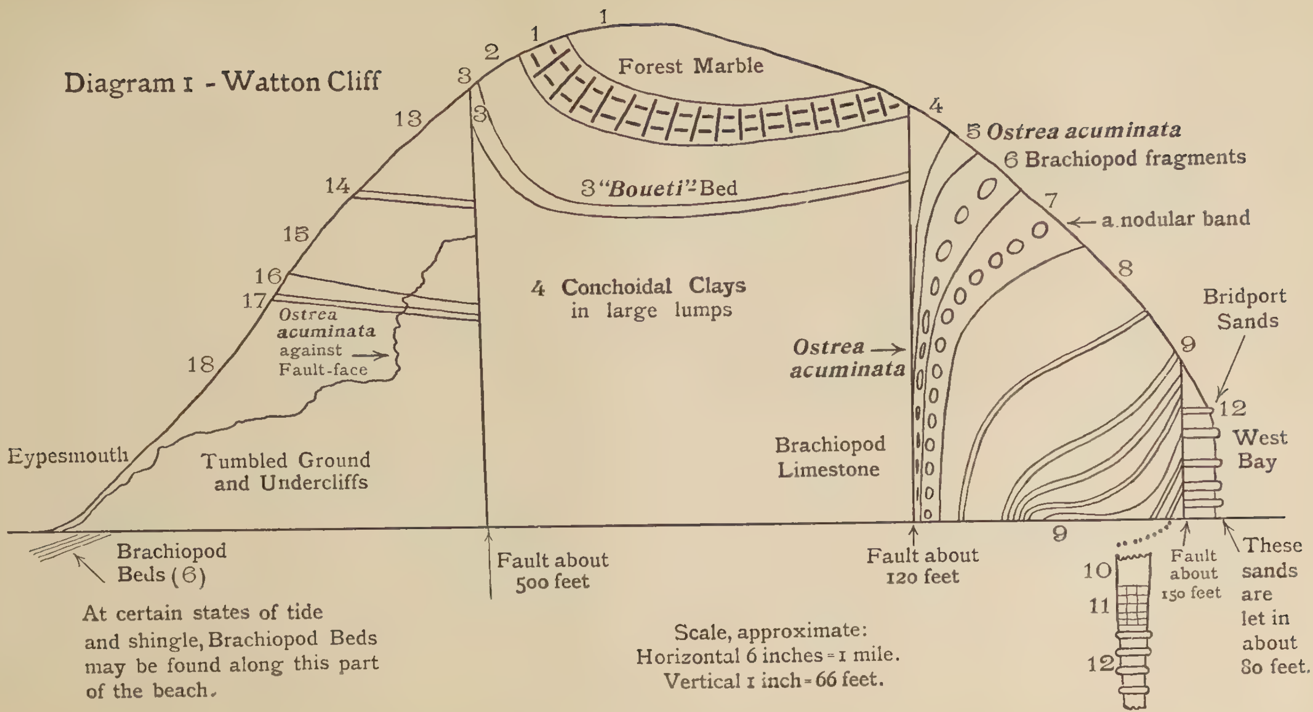
The accompanying diagram (1) embodies a general sketch of Watton Cliff.

[1] Name given from their occurrence at Thorncombe Beacon.

[2] The equivalent of this at Down Cliffs was wrongly placed in my section (I, 5, p. 66) copied from Day, and the thickness omitted. The *f* should be just above *g* there, and the thickness ($6\frac{1}{2}$ feet) should be put opposite; see E. C. H. Day, III, p. 285.

[3] From their occurrence at Down Cliffs; see Day, as above.

Diagram I - Watton Cliff



At certain states of tide and shingle, Brachiopod Beds may be found along this part of the beach.

Scale, approximate:
Horizontal 6 inches = 1 mile.
Vertical 1 inch = 66 feet.

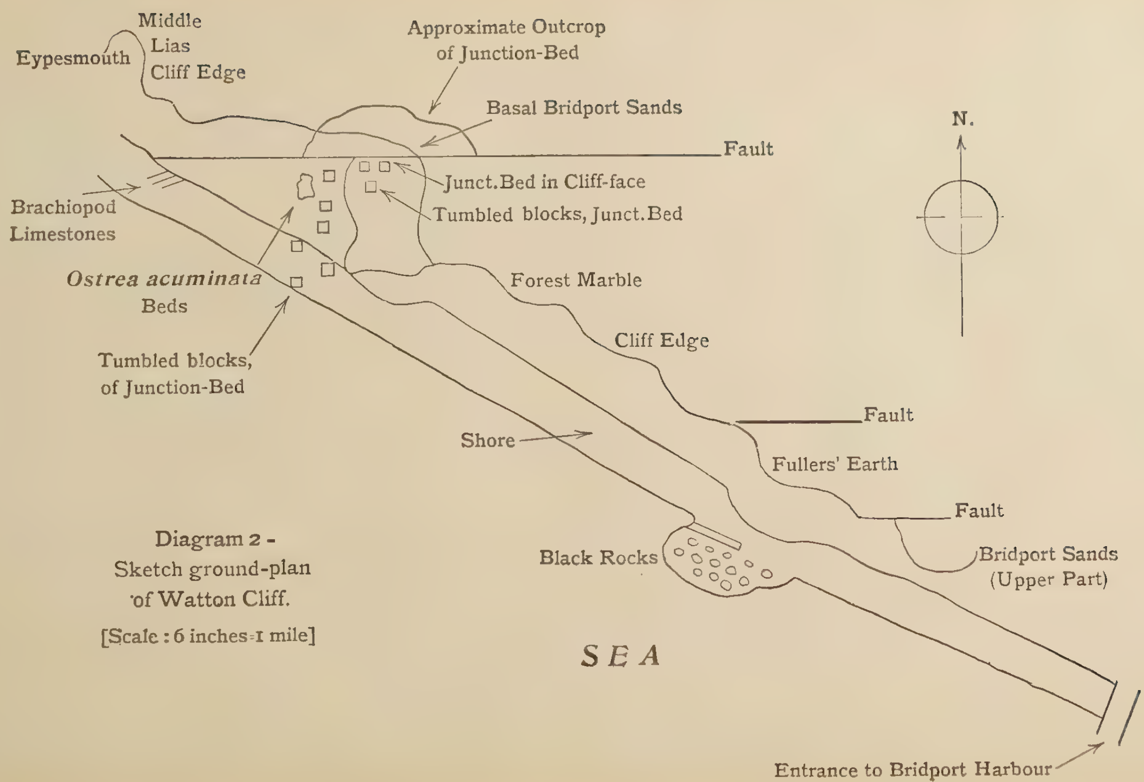


Diagram 2 -
Sketch ground-plan
of Watton Cliff.
[Scale : 6 inches=1 mile]

The general features of the strata of this cliff will be discussed in a later paper. Now the Junction-Bed claims attention.

Diagram 3.—*Watton Cliff, near Bridport (Dorset), view of Junction-Bed (Watton Bed) in face, looking northwards.*

1.	Bluish sandy clay, with hard beds at intervals. Basal Bridport Sands or Down - Cliff Clay equivalent.	Difference in colour between Beds 1 & 3 very noticeable in the cliff-face.
2.	Junction-Bed. Hard compact block.	
3.	Yellow sands of Middle Lias, faced on a very steep batter by an irony conglomerate-bed, containing belemnites (slickensided), ammonites (*Dumortieria*, and some Whitbian species). Some 20 feet of fault-face visible.	
4.	Blue Clay. Under about a foot of clay is Day's *margaritatus*-bed—a bluish marly stone: fallen blocks may be seen under the cliff on the left.	

Diagram 4.

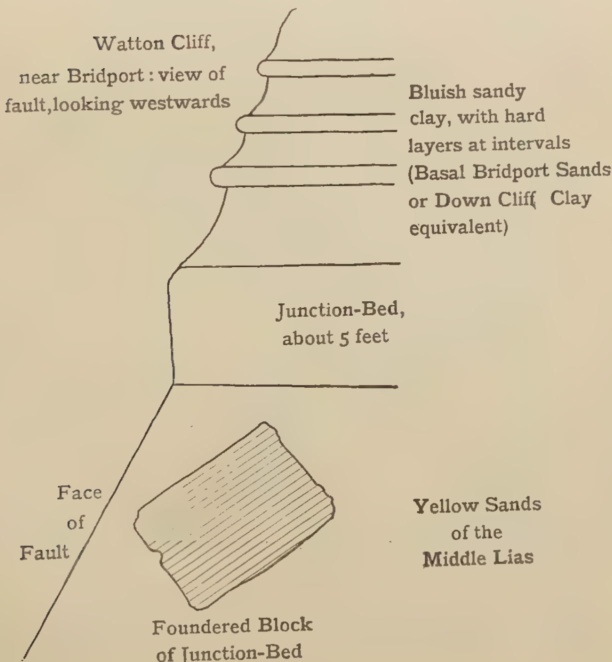
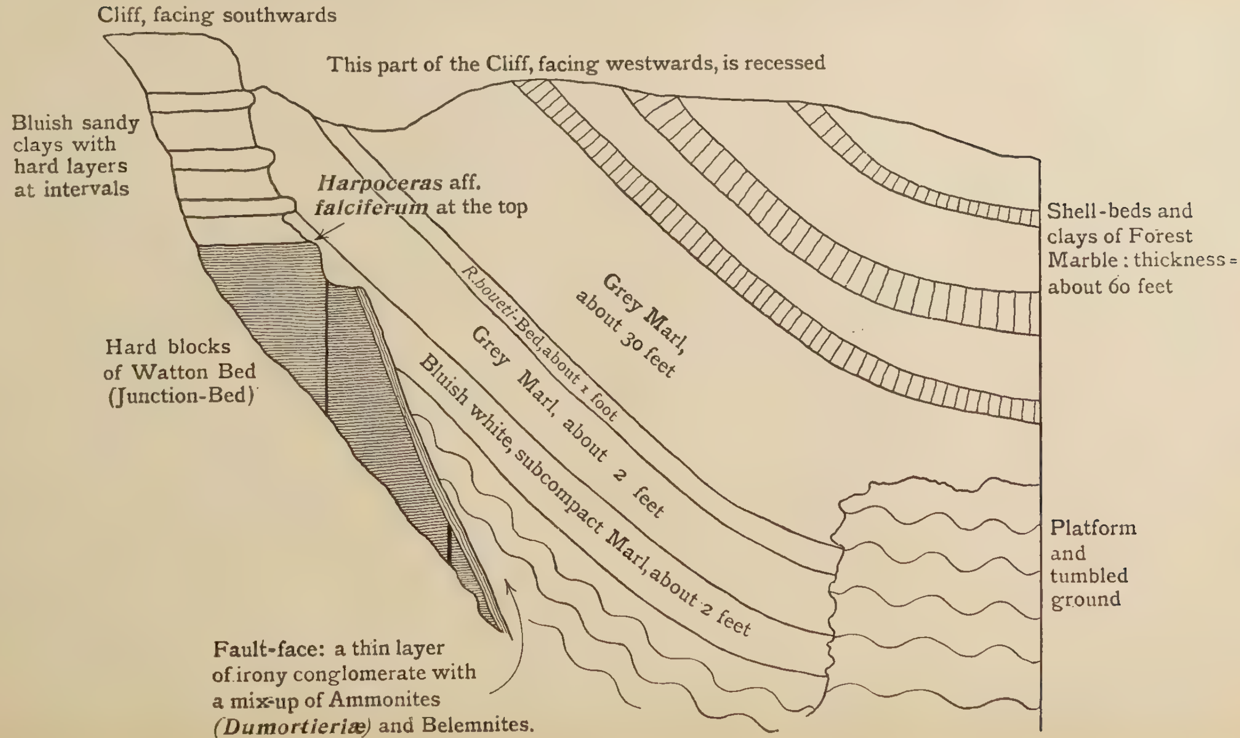


Diagram 5.—*Watton Cliff, near Bridport (Dorset) : view of fault looking eastwards.*



Diagrams 3, 4, & 5 are sketches to show the general position of the Junction-Bed. Of the face view it may be remarked that on the left, as the Junction-Bed runs out to the grassy slope of the cliff, it diminishes in thickness and seems to peter out at the surface: this is possibly due to solution by humic acid and the removal of the clayey capping, and it accounts for the bed not making any feature in the slope of the cliff. However, the bed was detected in the ploughed field immediately north of the fault-corner, a little way down the hill.

(B) The Junction-Bed of Watton Cliff, or, as it may more conveniently be called, the Watton Bed, is now described in detailed section, the result of my investigation. For the results of Mr. J. F. Jackson's examination Appendix I, p. 445, should be consulted.

Section II—Watton Cliff, near Bridport (Dorset). The Junction-Bed, generalized section with details from various fallen blocks.

		Thickness in feet	inches.
Layer 1.	Irony scale.[1] *Dumortieriæ* (*D.* aff. *regularis* S. Buckman, but more distant ribs, *D.* cf. *falcofila* Quenstedt sp.) and belemnites (of *tripartitus* style)	0	1
2.	White lithographic stone, weathered at the edge to look like paper-shales. Peripheries of ammonites of the *Grammoceras-striatulum* type, but scarce. A Dactyloid (No. 3002) cf. *Ammonites crassus* Dumortier, *non* Young & Bird, 'Bassin du Rhône' vol. iv (1874) pl. xxvii, figs. 5–7, *non cæt.* Similar forms occur in the *variabilis* beds of the Cotteswolds	0	6
3.	Yellow conglomerate, whiter towards the base. Broken fragments of *Grammoceras-striatulum* type, belemnites, *Tetrarhynchia thorncombiensis.* About 2 inches from the base *Dumortieria* sp.[2], and about at the base *Hildoceras* of *bifrons* type	0	7
4.	White lithographic stone like No. 2, with a conspicuous line of *Grammoceras* of *striatulum* type in section, showing peripheries and partly weathered—mostly in the topmost 2 inches. Section of a small *Nautilus* in the rock—an unusual form with a large umbilicus, a cordate whorl-section, the periphery somewhat sharpened. *Hammatoceras* of *insigne* type: gastropods	0	4
5.	Similar to No. 4, sharply irregular at the base. At one place the bed is 9 inches thick, at another 14 inches. Many specimens of *Grammoceras thouarsense-striatulum* type, about 4 inches from the top, in a somewhat muddy yellowish seam		

[1] In one case, irony scale presumably lacking, fine yellow sands rest on layer 2. They contain small belemnites like *B. quadricanaliculatus* (Quenstedt), which are also cemented to the top of layer 2.

[2] A micromorph with rounded whorls, undeveloped as to keel, ribs coarse; like the inner whorls of *Dumortieria novata* S. Buckman, but the ribs rather more approximate.

		Thickness in feet	*inches.*
	resting on lithographic stone—some of them are in the lithographic stone. These ammonites are mostly lying horizontal, but not in all cases.[1] At the same horizon as these ammonites a reversed gastropod, *Cirrus* sp. cf. '*Turbo bertholeti ?* D'Orbigny' Moore.[2] Nautilus with squared whorls.	9″ to 1′ 2″	
Layer 6.	Yellowish-brown shelly, more or less conglomeratic bed of variable thickness, running up into the bed above.[3] The variation in thickness seems to be due to a bodily transported block of the *Tetrarhynchia-thorncombiensis* Bed deposited in this layer; specimens of this species broken and whole; belemnites. This bed rests upon yellowish shales containing peculiar micromorph Hildoceratid ammonites (see p. 408)	1′ 1″ to 8″	
7.	Partly conglomerate, that is, broken up *T. thorncombiensis* Bed redeposited, and partly lithographic stone. Small Dactyloid ammonites; at the top *Rhynchonella* cf. *moorei* Davidson—a flattish form, subcircular, with coarse ribs, rectimarginate. This is the horizon yielding *T. thorncombiensis* in a fallen block on the lowest platform under the cliff, and *Thecidellæ* on the weathered top-face............	0	8
8.	Lithographic stone	0	3
9.	More or less conglomeratic with a pink tinge, some yellow sand-rock	0	5
10.	Lithographic stone	0	6
	Total	5	5

Remarks on the above section.—Fallen blocks gave a thickness of about 5 feet 6 inches, and a block measured *in situ* in the cliff-face gave a similar thickness. Attached to the upper surface of some blocks there is a certain portion of sandy deposit which really belongs to the sandy marls above (see diagram 3).

The irony scale which forms the top of the Junction-Bed is very noticeable in the fault-face, where this is formed by a partly foundered block (see diagram 5, p. 386). In this scale were found fragments of *Dumortieria*, and there are slickensided belemnites. From this scale on a block in the cliff I obtained a broken and worn fragment of *Harpoceras* of *mulgravium* type, and another example came from this top irony scale of a fallen block.

Blocks of the Junction-Bed on the beach gave the following information. Towards the base of blocks, especially where polished by wave-action, the stone has a pink tinge very suggestive of the pink stone (*bifrons*) of the Western Cliffs.[4] Some matrix suggestive of *spinatum* marlstone was seen, but no fossils. A large *Harpoceras* of *mulgravium* type was obtained from the base of a block—the specimen was in fair condition, but was not lying

[1] From 'about middle of Watton Bed,' which would be this layer 5, two examples of *Stolmorhynchia bothenhamptonensis* (Walker) with a yellowish-white matrix.

[2] VII, p. 210 & pl. vi, figs. 7–8.

[3] From a loose block examples of *Stolmorhynchia bouchardi* Davidson, with a yellow matrix (presumably this bed), were obtained.

[4] I, 5, p. 64.

horizontally. A striate *Nautilus* of fair size was obtained from just below the [lower?] *striatulum* layer and a little *Zeilleria* (the so-called '*Waldheimia lycetti*') was obtained from this *striatulum* layer.

A comparison of this detailed section of the Watton Bed with that of the Junction-Bed in the cliffs west of Eypesmouth (Thorncombe Beacon, Doghus and Down Cliffs), as recorded in my previous paper,[1] will show how unlike the former is to the latter.

Thus the former is as much as $5\frac{1}{2}$ feet thick, whereas the latter is about 2 feet, although it may amount to somewhat more occasionally. The former is mainly made up of a lithographic stone with *Grammoceras-striatulum* types, derived examples of *Tetrarhynchia thorncombiensis*, and derived lumps of this *Rhynchonella* Bed. The latter shows sometimes about 2 inches of the *striatulum* layer, while the *T.-thorncombiensis* Bed is, according to my measurements, some 8 feet below the Junction-Bed at Thorncombe Beacon: according to my interpretation of Day's measurements at Down Cliffs,[2] it is more than 18 feet below, about which something will be said later.

Further, the Watton Bed shows no sign of Marlstone,[3] which is, when present, a richly fossiliferous horizon in the Western Cliffs; nor did I find any strata with the *bifrons* type of ammonite—only examples redeposited along with *striatulum* forms.

In the Watton Bed there are certain peculiar Whitbian ammonites—unfortunately in fragmentary condition, mainly only body-chambers. Nothing of such forms has been noted for the Junction-Bed of the Western Cliffs; but, of course, all the ammonite fauna of that deposit has not been fully examined, for removal of this matrix is very tedious. In the Watton Bed, however, there were enough specimens to attract attention at once, and yet I imagine that they are unusual for Whitbian deposits of the South of England. About that it is inadvisable to speak too positively as yet—first, because these ammonites require study; and secondly, because the Whitbian ammonite fauna of the South of England has been very imperfectly illustrated. These ammonites have something of the appearance of certain small species from the Jet-Rock of Yorkshire—at any rate, they suggest an early date in Whitbian, about *exaratum*, or even before that.[4] The *Thecidellæ*, which are just below them, call to mind the micro-brachiopod horizon below the Fish- and Insect-Beds of the South-West of England.

These matters will require further study later, see p. 400.

[1] I, 5, p. 64. [2] III, p. 285.

[3] I, 5, p. 65. Later observations of a fallen block suggested some Marlstone matrix used up, but no fossils were found. Naturally, blocks may vary considerably in their constituents.

[4] Curiously enough, Mr. J. F. Jackson has found similar ammonites at a higher horizon in the Watton Bed; they are in a much better state of preservation, and have a white matrix.

III. The Dating of the Junction-Bed of Watton Cliff.

(A) Upper Lias Succession in other Areas.

In order to understand the evidence of the Junction-Bed of Watton Cliff, it is necessary to investigate the stratal and faunal sequences of other areas. And, as this Junction-Bed contains fauna belonging to dates which range from pre-*spinatum* to *Dumortieria*—in other words, contains fauna of Domerian, Whitbian, and Yeovilian ages—it is necessary to make a somewhat extended investigation (1) as to the sequence of the Upper Lias (Whitbian, Yeovilian); (2) as to the Middle Lias of about *spinatum* (Domerian) date in the Junction-Bed elsewhere; and (3) as to the Domerian pre-*spinatum* beds which are found in Thorncombe Beacon. First and most important, then, is the Upper Lias (Whitbian) succession, so far as the lower part of it is concerned. This is given in the following summaries.

I. Succession in Normandy (according to E. Eudes-Deslongchamps).[1]

[*bifrons-falciferum.*	Marnes moyennes. *Ammonites bifrons* [*Hildoceras* spp.] et *serpentinus* [=*Harpoceras falciferum* et aff.].
murleyi ?	Argile à poissons.
Leptæna. globulina.]	Couches à *Leptæna*: *L. moorei*, *L. liasina*, *Terebratula globulina*, *Rhynchonella pygmæa*.

II. Succession in the Early Part of the Upper Lias of Ilminster (according to Charles Moore, 1867).[2]

[*bouchardi-murleyi.*]	(6) 'Zone of *Rhynchonella bouchardii*.'	
	(5) 'The Saurian and Fish Zone.'	
'The *Leptæna* Beds.'	(4) 'Zone of *Leptæna* [*Pseudokingena*] *granulosa*, *Spirifera ilminsterensis*, and *Zellania liassica*.'	
	(3) 'Zone of *Alaria unispinosa*.' 'Zone of *Thecidium rusticum*.'	
	(2) 'Zone of *Leptæna bouchardii*, *L. moorei*' (the first abundant, the second rare).	'*Terebratula globulina*. *Rhynchonella pygmæa*.'
	(1) 'Zone of *Leptæna bouchardii*, *L. moorei*' (and several other *Leptænæ*), p. 170.	

For the time when it was written this is a remarkably detailed record, to our present advantage, and we may be grateful to Moore for it. But it is interesting to note that, although he gives so much detail with regard to these lower beds, he groups the sixteen beds above his Saurian zone under the one term 'The Upper Cephalopoda Beds,' making only one zone of the basal 2 inches, and leaving the rest unseparated. Yet now we have those beds separated out into some eight or nine zones. There is reason to suppose that the zone of *Rhynchonella bouchardi* was rightly separated from these by Moore, and, at any rate for recording purposes, it should be kept distinct. Moore shows that it is post-Saurian Bed—that is post-*murleyi*, if the Alderton Fish-Beds

[1] V, pp. 60 *et seqq.*
[2] VII, pp. 132, 170 *et seqq.*

are on the same horizon as his Saurian Bed, which seems likely, but is not yet definitely proved. From Moore's evidence it may be judged that the *Rhynchonella-bouchardi* Zone is pre-*falciferum*; but how much earlier? Was it pre-*exaratum*? Its absence from Yorkshire and the failure of *exaratum*-like ammonites from the South-West of England, where *Rhynchonella bouchardi* is not unusual, seem to indicate that it is not actually of *exaratum* date.

III. Succession in the Upper Lias of Stroud, Gloucestershire (according to E. Witchell).[1]

[*bifrons-falciferum.*	[*Ammonites*] *bifrons*, *A. serpentinus* [*Harpoceras falciferum* et aff.], *A. communis* [*Dactylioceras* spp.]. Fish-remains rare.
globulina.]	*Terebratula globulina* and *Rhynchonella pygmæa* in considerable numbers.

IV. Succession in the Upper Lias of Churchdown, Gloucestershire (according to F. Smithe, cited by E. Witchell).[2]

	'Crustacean' [Bed].
[*murleyi.*	'Fish-Bed.'
	'Alga-Bed.'
Leptæna.	'*Leptæna* Bed.'
globulina.]	'*Terebratula globulina*' [Bed].

V. Succession in the Upper Lias at Alderton (Dumbleton), summarized from various authorities[3] and from personal observations.

[*bifrons-falciferum.*	3. Shales with *Hildoceras*, *Harpoceras*, *Dactylioceras*, 44 feet.
murleyi.	2. Saurian, Fish- and Insect-Bed: Light-ochre Fissile Bed; *Ammonites murleyi*,[4] 1 foot.
globulina.]	1. Paper-shales, '*Leptæna* Shales,' *Terebratula globulina*, *Rhynchonella pygmæa*, 15 feet.

This is the northernmost point, I think, at which the small *Terebratula* and *Rhynchonella* have been observed; but their range is wide, as it extends into Normandy. Therefore they are good for dating. It is doubtful whether *Leptæna* has been found at Alderton (Dumbleton). Moore mentioned the *Leptæna* Clays as 15 feet thick there; but he may have recognized them only by the presence of the *Terebratula* and *Rhynchonella*. H. B. Woodward's citation of *Leptæna* from these clays may have no other basis than Moore's remark. I have collected the *Terebratula* and *Rhynchonella*, but have seen no other brachiopods there, and Mr. Linsdall Richardson mentions the two former, though he does not cite *Leptæna*.[5] Witchell's evidence from Stroud is to the same effect.

[1] XIII, p. 25. [2] XIII, p. 26.
[3] VII, p. 149; IX, p. 56; X, 1, p. 36; XIV, p. 267.
[4] The following species of 'Ammonites murleyi' have now been published. *Murleyiceras murleyi* (I, 8, ccxvi), *M. forte* (ccxlv), *M. aptum* (cccxvi).
[5] IX, 1, p. 57.

The point is that, if the various species of *Leptæna* are absent from the thick deposit of Alderton, which contains the minute *Terebratula* and *Rhynchonella*, it may be because the *Leptæna*-Beds are not really synchronous with the *globulina* beds, although in places (Ilminster and Normandy) the two may be mixed owing to paucity of sedimentation. Smithe's record at Churchdown supplies some evidence in this connexion, giving the *globulina*-bed below *Leptæna*. The data are insufficient, and further research is required. But they show that, in the case of Churchdown, records from the *Leptæna* Bed and from the *globulina* bed should be kept separate, and that while the strata of Alderton (Dumbleton) and Stroud are known to be of *globulina* date, they are not known to be of *Leptæna* date. The same may be the case with other localities whence *Leptæna* Clays have been cited.

The next piece of evidence for the separation of the *Leptæna* and *globulina* beds would be to find the former without the latter. Moore's records of his finds at Whatley come in here: he obtained three species of *Leptæna*, but makes no mention of *Terebratula globulina* nor of *Rhynchonella pygmæa*.[1] He gives a similar result for Sandford [Orcas, Somerset].

Therefore the faunal analysis works out as follows:—

	Normandy.	Somerset.			Gloucestershire.		
	Caen.	Ilminster.	Sandford Orcas.	Whatley.	Stroud.	Churchdown.	Alderton.
Leptæna	×	×	×	×	...	×	?
T. globulina ...	×	×	...	...	×	×	×

These records give at least sufficient reason for a theory of two deposits at two different dates. At any rate, it is necessary to keep them distinct for recording purposes, and not to credit a locality with the possession of the *Leptæna* Beds[2] merely on the evidence of the *Terebratula* and *Rhynchonella*.

Similar mistakes to this we have all made in the past—a relic of the old teaching, which consistently obstructed all increase in the number of names—of zones, of genera, or of species. That was a wrong doctrine; because it will now give much more trouble than the other course, and impairs the value of many old records. It is to be hoped that what may be called the 'analytical method' will be pursued in the future, even if it does involve the use of many names.

A consideration of these Upper Lias records suggests the following succession; but it is incomplete. There are gaps (non-

[1] VII, p. 157.

[2] The *Leptæna* Beds have a wide range—the South-West of England, Normandy, Würtemberg; also Sicily, according to the title of a paper by G. G. Gemmellaro, 'Sugli Strati con *Leptæna* nel Lias Superiore di Sicilia' Boll. Com. Geol. Ital. vol. xvii (1886) pp. 156, 341.

sequences), as is known from other areas, and where these really occur is a matter of some surmise :—

falciferum,
bouchardi,
murleyi,
granulosa,
Alaria,
Thecidella rustica,
Leptæna,
globulina,
spinatum.

(B) Additional Details concerning the Junction-Bed of Thorncombe Beacon.

One of the most remarkable features of the Junction-Bed is that it may always spring surprises in the matter of its faunal contents. This apparently arises from the fact that fragments of so many different beds have been preserved. These fragments are in many cases quite small, and in other cases it would seem that the fragments themselves were disintegrated, but that some of their contents became incorporated in other strata.

During one visit I was fortunate enough to find a small block in which were preserved various specimens of *Rhynchonella serrata* and like forms (*Prionorhynchia* spp.) in a sort of pale Marlstone-Rock matrix. This presumably is only a fragment of a once widespread bed. One may search many of the ordinary Marlstone blocks under Thorncombe without finding it. Walker found many specimens of *Rh. serrata* at the temporary exposure near Bothenhampton. Moore says that near Ilminster (Somerset) the species is found only at Moolham [1]; these Somerset and Dorset localities are, I think, the only places where the fossil is known in England, and consequently destruction of this bed must have been considerable. On the Continent a species allied to *Rh. serrata*—*Prionorhynchia quinqueplicata* (Zieten) is found in Würtemberg, indicating, perhaps, that an original spread of the bed was to that country. This species is also found in England with *Rh. serrata*.

From the same block I obtained a remarkable Terebratulid—somewhat of *Terebratula punctata* style, but anteriorly sulcate, and therefore an inverted form. Further search for other blocks to yield another example was quite unsuccessful. During my visit in 1920 I could not find a single block showing the *serrata* bed. Mr. Jackson, however, has another inverted example, though it is a different species. I hope to deal with these in a future palæontological portion of this paper.

Rhynchonellids, small, rather flat, with few coarse plicæ, were found in this bed : such forms have passed by the names *Rhynchonella egretta*, *Rh. fallax*, but the identifications are open to doubt. Also from this block I extracted examples of (or allied to)

[1] VII, p. 164.

Rhynchonella bouchardi (*Stolmorhynchia* spp.). As *Rh. bouchardi* was, according to Moore, of post Saurian-bed date, this seems to show that the *serrata* bed and the *bouchardi* bed were being destroyed together, and that some of their fossils were being mixed up. The *serrata* bed holds evidence of such a mix-up, for in this same block were *Rhynchonella* (*Homœorhynchia*) *acuta*, the large form, *Quadratirhynchia crassimedia*,[1] *Q.* aff. *sphæroidalis*,[2] and other species which properly belong to the lower bed—the brown marlstone. I have seen *Rhynchonella acuta* in the Upper Lias part of the Junction-Bed.

For successful collecting, it is important to note the distinction in matrix between the pale, rather soft *serrata* bed and the dark hard Marlstone below, as it is of little use to look in the latter for the special fossils of the former. The hard Marlstone is a fairly constant bed at the base of blocks of Junction-Bed: the *serrata* bed is rarely found, having been denuded from the Marlstone before the Upper Lias was cemented to it. The planed-off top of the Marlstone shows the denudation: it is also a guide as to which is the upper part of odd Marlstone blocks.

However, this lower Marlstone is not necessarily homogeneous, and may be compounded of beds of various dates. In my former paper I mentioned my lack of success in finding Day's *Pleurotomaria* Bed.[3] During my visit in 1920 I was successful. A Marlstone block about 1 foot thick gave the following :—

(*a*) Hard, finely ironshot, blue marlstone decomposing to a rusty brown, about 3 or 4 inches.

(*b*) Hard ironshot in the middle of the bed.

(*c*) Hard ironshot in the lower part of the bed, enclosing big blue sandstone-pebbles; they look like fragments of the Starfish-Bed. See later, p 397.

The following is a rough sketch of the faunal contents :—

Upper 3 or 4 inches—*Pleurotomaria* spp. Specimens so crowded that, in the course of the extraction of one, others were broken. Mainly acuminate species, but one or two more depressed. See p. 400.

Just under the *Pleurotomariæ* various species of *Paltopleuroceras* and *Quadratirhynchia crassimedia* occur.

In about the middle of the block a fragment of *Ammonites* cf. *kurrianus* Oppel and various lamellibranchs were found.

In the lower part of the block, a depressed *Pleurotomaria* was seen.

In another small block—a rather soft brown matrix, quite unfamiliar—I found a single small example of another inverted Terebratulid: it is like *Terebratula bakeriæ* Davidson, which comes from the *acutum* bed (Transition-Bed) of Northamptonshire, but very rarely, only two or three specimens being known.[4]

[1] I, 6, pl. xiii, fig. 3 *a*. [2] I, 6, pl. xiii, fig. 2. [3] I, 5, p. 83.

[4] Its rarity may be due to the fact that it really comes in the bottom layer of the Transition-Bed—the *athleticum* horizon, which has been almost destroyed in Northamptonshire. The finding of a like form in the Junction-Bed supports this idea, for *Tiltoniceras* has not been found in this bed, although there are evidences of the *athleticum* fauna.

Edward Wilson found, in the Junction-Bed of the Dorset coast some 25 years ago, when in company with Mr. Tutcher, a similar species: the specimen is now in the Bristol Museum. Accompanying my example were some unfamiliar Harpoceratoid ammonites which will require further investigation. This bed possibly yielded those Dactyliocerates, of about Transition-Bed date, which have been obtained from the Dorset coast.[1]

We may now return to *Rhynchonella bouchardi*: three or four examples can sometimes be obtained from a small lump—from rock which belongs to the base of the Upper Lias: that is to say, it is to be sought for in the blocks immediately above the Marlstone, which is congruous with Moore's post-Saurian-Bed position. It also comes from the Watton Bed, from Ilminster, South Petherton, and other places. It is a form of fairly wide distribution: Thomas Davidson figures an example from Cromarty (Scotland); Eudes-Deslongchamps mentions it from Normandy. But all mention and figures of it are not to be trusted. I seem to recollect the name being applied to some figured examples which have nothing to do with Davidson's species. And I have my doubts about the Cromarty shell.

The widespread occurrence of strata with *Rhynchonella bouchardi* indicates a period of perhaps greater quiescence after their deposition than had been the case with some previous deposits. But the *bouchardi* deposit did not escape wholly, for there are some large areas without it—I think that the Cotteswolds might be cited; and in some cases where *Rh. bouchardi* is found, it has certainly been taken from its own bed and redeposited.

It is from such evidence as this—some of it particularly fragmentary—that a reconstruction of the course of events in the matter of deposition had to be made.

The Dorset coast, then, seems to supply evidence, by fossils and sometimes by fragments of strata, for the following sequence:—

(6) *Harpoceras-falciferum* Bed.
(5) *Rhynchonella-bouchardi* Bed.
(4) *Dactylioceras-athleticum* Bed.
(3) *Rhynchonella-serrata* Bed.
(2) *Pleurotomaria* Bed.
(1) *Spinatum* Bed.

(C) The Middle Lias (Domerian) of Thorncombe Beacon.

As the Junction-Bed of Watton Cliff contains Domerian strata of earlier date than those found in the bed under the Western Cliffs, it becomes necessary to give a short summary of these deposits. The information is required for several reasons, as will be seen later.

Blocks and pebbles scattered along the shore from under Thorncombe Beacon to Eypesmouth show various matrices, and contain many different fossils. In fact, some of the small pebbles

[1] I, 5, p. 83.

yield quite a rich harvest, and are well worthy of investigation. Only in certain cases have I been able to attack the beds in the cliffs, a very laborious and unsatisfactory task, and therefore my information is not so complete as it might be. But, with the help of Day's section, it may be possible to work out the main sequence—sufficiently, at any rate, for present purposes.

Table I, below, gives in the two left-hand columns a summary of Day's information, with my interpretation of his fossil names in square brackets, and in the two right-hand columns are the details which I have collected—the sequence and position in certain cases being supposititious.

TABLE I—DOMERIAN (PRE-*SPINATUM*) DEPOSITS, THORNCOMBE BEACON.

Day's Details.		S. S. Buckman's Details.	
Strata.	Fauna.	Strata.	Fauna.
Brown sands and sandstones. (Blocks of indurated sand.)	*Ammonites. spinatus* [*Amaltheus armiger ?*] *Ammonites bechei.* [*Anisoloboceras nautiliforme.*]	Thorncombe Sands with *Tetrarhynchia-thorncombiensis* Bed. (The '*Rhynchonella-northamptonensis*' Bed.) Compact brown marly rock with numerous Rhynchonellids, which weather out cleanly.	*Tetrarhynchia thorncombiensis*= '*Rhynchonella northamptonensis*' (auctt.) Walker in Davidson. A thin sharp-edged *Zeilleria.*
Margaritatus-Stone. (*Margaritatus*-Bed.)	*Ammonites margaritatus.* [*Amaltheus* cf. *amaltheus* and other species.] *A. fimbriatus.* [*Lytoceras fimbriatum* Wright (*non* Sowerby), Mon. Lias Amm. 1883, pls. lxxi, lxxii= *L. postfimbriatum* Prinz-Vadasz.]	*Margaritatus* Bed: Yellowish-brown, blue-centred, marly stone.	*Amaltheus* spp., and Lytoceratid, as cited in col. 2.
Grey and brown sands with nodules.	'Masses of *Rhynchonellæ* of small size.' 'In some places lumps composed chiefly of the stems and arms of *Pentacrinus johnsonii* Austin.'	Down-Cliff Sands with massive sandstone-bed. Pale yellow with blue centre. Mainly unfossiliferous, but fossils crowded in certain small portions which resist wave-action: these supply the fossiliferous pebbles. The yellow pebbles can be assigned to this bed with fair certainty; but the blue may be mistaken for Starfish-Bed or for Shell-Bed, or *vice versa.*	Numerous small *Rhynchonellæ* of cuboidal form, with sharp-cut ribs. Some small Amaltheids in the yellow stone. Many small Amaltheids in blue pebbles. Pebbles with numerous fragments of crinoids in a blue sandstone perhaps belong here.

Day's Details. Strata.	Fauna.	S. S. Buckman's Details. Strata.	Fauna.
The Starfish-Bed.	*Ophioderma.*	Blue somewhat marly sandstone.	*Ophioderma.*
The Shell-Bed immediately underlies the Starfish-Bed.	Rich in Conchifera. *Ammonites margaritatus.* [*Amaltheus* spp.] *A. thouarsensis.* [*Seguenziceras* cf. *algovianum.*]		
Mudstone, with nodular concretions and shells.		The black nodule-bed. (Bluish marly stone, with black nodules.)	Amaltheids.
		Light-blue clay.	
Marls, with a layer of small nodules.	Ammonites of several species.	Dark blue conchoidal clay, with two lines of small nodules near the top.	Fragmentary Amaltheids in the nodules. Body-chambers of *Amaltheus* aff. *clevelandicus*, *Ammonites* cf. *boscensis* and like forms in the clay in line with the nodules (*Tragophylloceras* aff. *loscombei* J. Sowerby sp. [derived?]).
The Three Tiers.	*A. margaritatus.* *A. loscombii.* *A. fimbriatus.*	The Three Tiers form 'The Ledges,' which show on the foreshore under the eastern end of Thorncombe Beacon at low tide. (Hard blue sandstone.)	

Most of the hard beds mentioned in Table I are separated by thick masses of unfossiliferous or poorly fossiliferous sands or clays (see Day). From the Junction-Bed to his 'blocks of indurated sand,' which I take to be the *T.-thorncombiensis* Bed, Day makes 18 feet at Down Cliffs and from the Junction-Bed to the Marlstone-Bed 92½ feet; whereas my measurements at Thorncombe Beacon give 8 and 68 feet respectively. More will be said about this difference presently, for it is a rather interesting point.

In certain pebbles of blue sandy matrix I found small Amaltheids, which are very similar, if not identical, with *Amaltheus lævis* (Quenstedt), and their matrix certainly recalls that of the Scalpa Sandstone. In my first paper on Jurassic Chronology I proposed a zone of *Amaltheus lævis*,[1] placing it directly beneath that of *Paltopleuroceras spinatum*. Recent researches have tended to confirm the value of the zone, but have raised considerable doubt as to its position. According to the Thorncombe evidence the first zone below that of *P. spinatum* is that of the so-called *Rhynchonella northamptonensis* (*Tetrarhynchia thorncombiensis*) and the next is that of the *margaritatus* bed with large examples of *Amaltheus*. The specimens supposed to be *A. lævis* may come from the

[1] I, 7, p. 262.

massive sandstone-beds of the Down-Cliff Sands at the latest, but may come from the Starfish-Bed or the Shell-Bed. No sign of the rest of the fauna which was found in the Scalpa Sandstone in the same matrix as that of *Amaltheus lævis* was seen at Thorncombe.

If *A. lævis* comes from the Starfish-Bed and *Seguenziceras* from the immediately subjacent Shell-Bed, while there seems to be some 200 feet between *A. lævis* and *Seguenziceras* at Raasay in the Scalpa Sandstone,[1] a very interesting position would be reached, but one quite analogous to what is found in other cases. Some 200 feet would have to be added where now is little or no deposit. The already thick strata of the Domerian on the Dorset coast would still lack representatives of a time-interval equal to some 200 feet of deposit. The length of time required for the deposition of the Domerian is thus likely to increase to a large figure: it is already considerable.

These points cannot be pursued now, but they show where further work is required. It is obvious that the complication of the Domerian succession will be much greater than has been expected, and that the dating of the Scalpa Sandstone may have to be considerably modified. But that will not be at all a simple matter: it will immediately raise many other questions, among them perhaps that of local denudation of the Scalpa Sandstone—and that presents difficulties.

The Domerian succession disclosed by Thorncombe may be stated as follows:—

(7) *Paltopleuroceras spinatum.*
(6) '*Tetrarhynchia thorncombiensis.*'
(5) Lytoceratid (the *margaritatus* bed).
(4) Cuboidal Rhynchonellids.
(3) Starfish-Bed (=? *Amaltheus lævis*).
(2) *Seguenziceras.*
(1) *Amaltheus clevelandicus.*

This sequence is, in all probability, incomplete for the Domerian strata of Thorncombe Beacon—because, for one thing, it has not yet been possible to extract from their matrix all the specimens collected,—and it is certainly incomplete so far as the full Domerian sequence is concerned. Faunal elements of the Hebrides and Yorkshire are missing, and will have to be accounted for; but, more important still, faunal elements of the Ilminster district and of Normandy—that is, faunal elements immediately north and south of Dorset—are lacking.

Some interesting examples of this are the following:—*Aulacothyris resupinata* and *A. moorei* occur at Ilminster and in Normandy. The absence from the Dorset-coast sections of *Terebratula* [*Aulacothyris*] *resupinata* (including *T.* [*A.*] *moorei* presumably) is particularly noted by Day.[2] Walker mentions this, and says nothing to the contrary.[3] My experience is the

[1] I, 7, p. 261. [2] III, p. 293. [3] XII, p. 442.

same. Yet Walker found eight specimens of the first and one of the second at Bothenhampton. Now, it is fairly certain that these forms occupy a rather low position in the *spinatum* zone —may even indicate a deposit which is actually of pre-*spinatum* date. If so, the explanation of the geographical record is easy —this earlier bed, or some of its contents, is preserved at Bothenhampton; and the bed is certainly present at other places, but it and its contents have been lost from the coast-sections.

On the other hand, Walker notices particularly that not a fragment of *Rhynchonella acuta* rewarded his work at Bothenhampton. Considering that it is a not uncommon fossil at the coast-sections in certain cases, and that it is a usual fossil of Marlstone localities, this is rather remarkable—more especially as what seem to be its customary associates were found by Walker. Here further analyses may be particularly interesting, with this additional reason—that there are two forms of *Rh. acuta*—a small form, to which the name was originally applied, and a large form. There is reason to think that the small form is not actually the young (the brephomorph) of the large form, but that it is earlier in date—is an earlier stage (an anamorph) of the large form. If so, small forms and large could be used as chronological indices, the small form possibly marking a fairly early Marlstone (*spinatum*) date; while the large form certainly marks a particularly late date, although it must be earlier than *Rh. serrata*, for it occurs where the *serrata* deposit has been lost. Is it to be assumed that there was no record of either of these two dates at Bothenhampton?

It is, I think, correct to say that the small form ranges from the Dorset coast to the Hebrides; but, before such a statement could be made positively, a critical study would be necessary: for there must be a true brephomorph of the large form, and this must be so similar to the presumed adult small form that they would only be distinguishable by what would be regarded as very trivial features. This shows why it is so necessary in palæontology to be precise in noting and naming quite small details, if the full value from the different forms is to be obtained, so as rightly to apprehend what they indicate regarding the history of deposition and denudation. If small biological details be passed over without notice, much of considerable chronological value may be lost.

It follows, then, that if the idea be correct that the two differently-sized forms of *Rhynchonella acuta* indicate different dates, the finding of the large form may be taken as fair evidence for the later date; but the finding of the small form is not necessarily good evidence for the earlier date—not unless we work out precisely whether the small form is a brephomorph or an anamorph, a labour only to be accomplished when the respective distinguishing characters have been properly ascertained. Proof that the anamorph and the large form lived at different dates should be found by faunal analysis, as well as by direct observation. The former should reveal areas where the anamorph existed by itself without any trace of the large form;

while the latter would find small forms occupying strata at a lower horizon than the large forms. This shows how much scope there is for further work.

Mr. J. W. Tutcher has kindly supplied the following identifications of gastropods and scaphopods which I have been able to give him, as the result of chance collecting during various years at and near Thorncombe Beacon. Some of the labels require a little interpretation, because in earlier years I was necessarily less conversant with the details of the sequence or the matrices of odd blocks:—

'Junction-Bed, *bifrons* layer.'
Discohelix dunkeri Moore.
'Junction-Bed.'
Trochus nodulatus Moore.
'*Rhynchonella-serrata* Bed.'
Trochus lineatus Moore.
'*Pleurotomaria* Bed.' [See p. 394.]
Pleurotomaria mirabilis Deslongchamps.
Pleurotomaria cf. *subnodosa* Goldfuss = possibly the form recorded by Day as *P. precatoria* Deslongchamps.
'Marlstone' [= *spinatum*?].
Amberleya cf. *gaudryana* A. d'Orbigny.
'*Spinatum*.'
Trochus cf. *flexicostatus* Moore.
'Lower part of Marlstone' [see p. 394].
Pleurotomaria mirabilis Deslongchamps.
'*Margaritatus* zone' [= possibly the *T.-thorncombiensis* Bed].
Cryptænia cf. *solarioides* (J. Sowerby).
'*Margaritatus*' [possibly *margaritatus* bed].
Cerithium liassicum Moore.
Ataphrus cinctus Moore.
'Massive Sandstone-Bed.'
Turbo aciculus (Stoliczka).
Dentalium elongatum Moore.
'With *Amaltheus* cf. *lævis*, pebble on beach, near Eypesmouth.'
Dentalium elongatum Moore.
'Pebble on beach, Eypesmouth, below *margaritatus* [bed], possibly Starfish-Bed.'
Actæonina ilminsterensis Moore.

(D) Analyses of the Junction-Beds, and Theories as to the Watton Bed.

From the faunal sequences arrived at in the foregoing studies, and from the results which have been already obtained and published elsewhere,[1] it is possible to present a detailed list of successive hemeræ, noting at the same time which of these hemeræ are represented by the fauna of the Junction-Bed at various places. But, as a preliminary, it is advisable to present an epitome of Walker's section at Bothenhampton.

About 2 miles somewhat east by north of Watton Cliff was the site of an exposure of the Junction-Bed at Shipton Long Lane,

[1] I, 7, p. 276.

Bothenhampton, described by J. F. Walker in 1892.[1] The following may be constructed from his description :—

Section III—Shipton Long Lane, Bothenhampton (J. F. Walker).

			Thickness in feet.
	1.	'White stone. *Ammonites germani* [*germaini*] (D'Orbigny)'	1
[*striatulum.*]	2.	'Brown stone. *Ammonites (Grammoceras) thouarsensis* (D'Orbigny), *Rhynchonella jurensis* var. *bothenhamptonensis*'	1
[*bifrons.*] *falciferum.* *bouchardi.*	3.	'Brown conglomerate, often with pink stone at the base. *Ammonites (Hildoceras) bifrons*, worn specimens of *Harpoceras falciferum*, *Rhynchonella bouchardi*'........	2
Harpoceratoid (*serrata*). [*spinatum*].	4.	'Marlstone. *Rh. serrata*' in the upper 3 inches. '*Rh. tetrahedra*' and many other brachiopods in the lower part	1

The possible faunal sequence ascertained by the foregoing studies may now be given and results compared.[2]

Table II—Faunal Contents of the Junction-Bed.

		Localities.		
	Hemeræ.	Western Cliffs, Thorncombe, etc.	Bothenhampton.	Watton.
Yeovilian.	*moorei*			
	Catulloceras			
	Dumortieria	...	...	×
	Hammatoceras	...	?[3]	×
	dispansum			
	struckmanni			
	pedicum			
	eseri			
	striatulum	×	×	×
Whitbian.	*variabilis*			
	lilli	?		
	braunianum			
	fibulatum			
	bifrons	×	×	×
	subcarinata	...	...	×[4]
	pseudovatum			
	falciferum	×	×	×
	bouchardi	×	×	×
	exaratum	...	...	?[5]
	murleyi			
	tenuicostatum			
	Leptæna	...	...	?[6]
	globulina			
	acutum			
	athleticum	×		
	Harpoceratoid (*serrata* bed)	×	×	
Domerian.	*Pleurotomaria*	×		
	spinatum	×	×	
	T. thorncombiensis ...	...	...	×

[1] XII, p. 441.
[2] See also the hemeral table given in Appendix II.
[3] *Ammonites germaini.*
[4] Mr. Jackson's discovery.
[5] Small Hildoceratid ammonites.
[6] *Thecidellæ.*

Diagram 6.—*Lithology of the Junction-Bed*
(vertical scale : 1 inch = 2 feet).

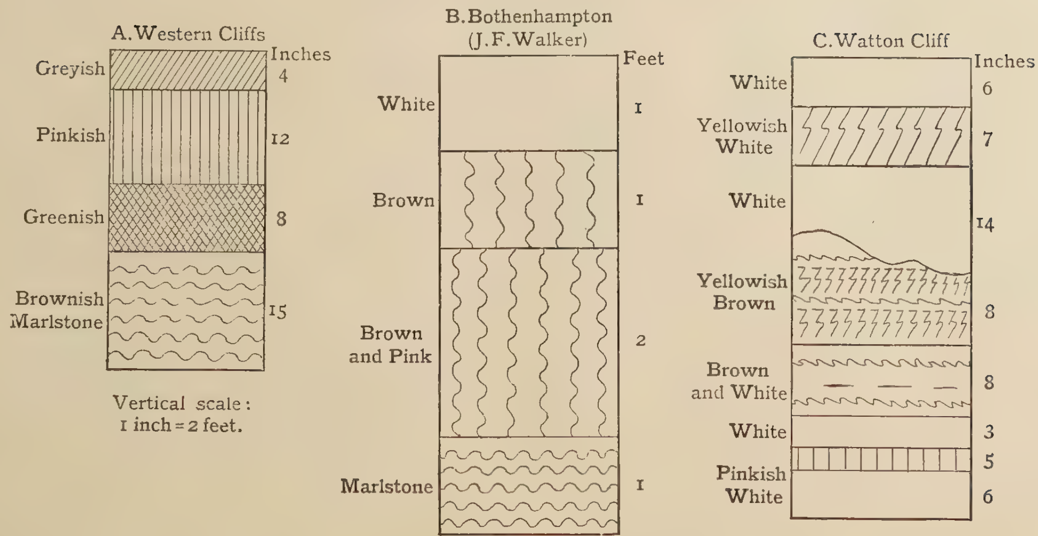


Table II records the faunal contents of the Junction-Bed at three places—I have drawn upon Mr. Jackson's evidence for one date (*subcarinatum*) in regard to Watton Cliff,—and it shows that, while there is substantial agreement between sections of the Western Cliffs and of Bothenhampton, yet that Watton Cliff differs considerably from both. This divergence is more noticeable than a mere list of fossil contents would indicate; for the points that are most strikingly in contrast between Watton Cliff and the other sections are, so far as Watton Cliff is concerned,

(1) The continuity through most of the Watton Bed of white-stone deposits.
(2) The considerable thickness of strata in which forms of *Grammoceras-striatulum* type are found.
(3) The presence of the *Thecidellæ* and unfamiliar Hildoceratids.
(4) The absence of the Marlstone-Rock bed—*serrata* and associated beds.
(5) The presence of the *Tetrarhynchia-thorncombiensis* Bed and many derived examples of that fossil.

These points are illustrated in Table II and diagrams 6 & 7.

The section at Bothenhampton is near a line of fault, parallel to and north of the Watton Cliff (Eype) Fault, heading in the direction of Thorncombe Beacon. The Junction-Bed of Bothenhampton reproduces the Thorncombe type, and shows Marlstone at the base. The Junction-Bed of Watton Cliff is closer to the axis of the Weymouth Anticline, and shows not only denudation and destruction of the Marlstone, but denudation carried down many feet lower—to below the *Tetrarhynchia-thorncombiensis* Bed (diagram 6, p. 402).

Now, Day's measurements (see above, p. 397) were made at Down Cliffs,[1] and by the increase in thickness it can be estimated that his exposure was some 4250 feet—approximately 6 furlongs—to the west of mine; it would, owing to the trend of the coast, take him some distance farther away from the axis of the Weymouth Anticline, and this would account for the greater thickness which he obtains between the Junction-Bed and the *margaritatus* bed. The following sections (diagram 8, p. 404) are placed in order from west to east, which direction, though not at true right angles to the anticlinal axis, is sufficient to illustrate the effect of it.

Thus in the Down-Cliffs section, as there are some 92 feet between the Junction-Bed and the *margaritatus* bed, in the middle section about 68 feet, and at Watton Cliff about 40 feet, the *Tetrarhynchia-thorncombiensis* Bed must have disappeared in the post-Marlstone denudation immediately east of Thorncombe Beacon, and the denudation has, at Watton Cliff, been carried down into the pre-*Tetrarhynchia-thorncombiensis*-Bed Sands (diagrams 8 & 9, pp. 404, 405).

The Marlstone Rock is only preserved at Thorncombe Beacon—

[1] There is reason to think that he took details, if not measurements, from Doghus as well as from Down Cliffs—the latter name originally covered both.

Diagram 7.—*Faunal comparison.*
(Vertical scale: 1 inch=2 feet.)

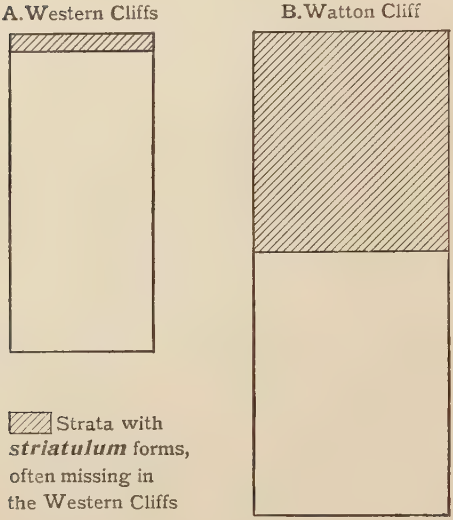


Diagram 8.—*Comparative sections at Thorncombe Beacon and Watton Cliff, on the scale of 30 feet to the inch.*

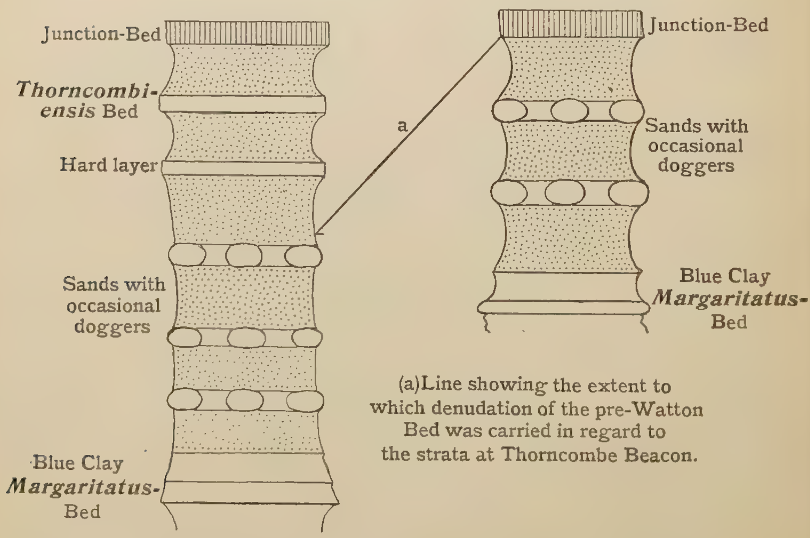
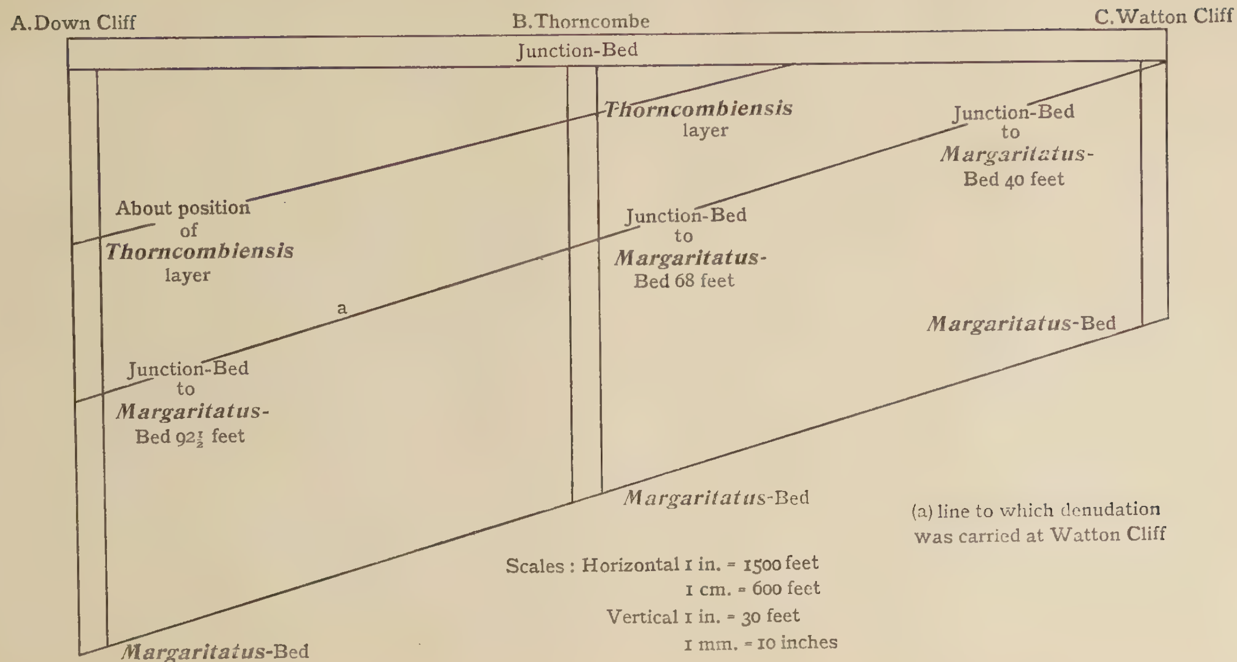


Diagram 9.—*Late Domerian denudation (or denudations), showing the effect of the Weymouth Anticline.*



not at Down Cliffs nor at Watton Cliff; this implies slight synclination of the Thorncombe area at the time of post-Marlstone denudation, just sufficient to preserve the thin bed. But there was a pre-Marlstone denudation—the presence of big blue sandstone-pebbles in the marlstone of the Junction-Bed of Thorncombe Beacon is evidence for that. The matrix of these pebbles suggests that they come from the Starfish-Bed; they certainly did not come from the *margaritatus* bed. Taking the data of denudation ascertained in the above sections—that is, about 30 feet to a mile,—then the Starfish-Bed was elevated to the line of erosion some $5\frac{1}{2}$ miles from Thorncombe Beacon. The main axis of the Weymouth Anticline runs out to sea some 7 miles south of Thorncombe Beacon. Another mile and a half would involve a further 45 feet, which would be insufficient to bring the Three Tiers—the next hard bed—to the surface along the axis.

The fact that the *margaritatus* bed is not found in pebbly condition, while the *Tetrarhynchia-thorncombiensis* Bed is found as pebbles in Watton Cliff (and probably it is the Starfish-Bed that furnished the pebbles for the Junction-Bed of Thorncombe Beacon), may suggest that movements of post-*margaritatus*-bed time allowed that bed to be covered up and protected by *thorncombiensis* or pre-*thorncombiensis*-bed deposits.

It will thus be seen that the Watton Bed is a deposit of exceptional interest geologically: it would also be rich palæontologically, if one had the means of breaking up the massive blocks. That it is different from the Thorncombe Beacon Junction-Bed, only about 7 furlongs away to the west, is due to the fact that it really belongs to a different piece of territory—to what was some half-mile nearer the anticlinal axis. This little transverse difference is more important than a considerable lateral distance, as is shown by the similarity of the Down Cliffs (Thorncombe) and Bothenhampton Junction-Beds, which are from $2\frac{1}{2}$ to 3 miles apart, but along the same line of fold.

The movements of the Weymouth Anticline and the distribution of strata which they produced in the English Channel suggest an interesting line of enquiry—as to the present-day distribution of strata out to sea. Some 20 years ago I collected certain data on the subject; but there has not yet been any opportunity of working out details, and the enquiry must be deferred for the present. However, such an enquiry should have a certain practical bearing. The distribution of areas of hard rocks—that is, areas of sandstone or limestone—is important to fishermen, as affording good ground for the setting of their lobster-pots. A geological investigation should indicate likely places to sound for such areas, and might lead to the discovery of some which are not yet known to the fishermen: they had, at the time I speak of, just made a chance discovery of a new ground.

To return to the Junction-Bed—it is evident from the various sections that the Weymouth Anticline was in a state of constant movement with consequent denudation making non-sequences.

Yet the non-sequences are not always synchronous in the different sections.

The main feature of the Watton Bed is the amount of deposit containing forms of *Grammoceras-striatulum* type, which, however, there is reason to suppose, are redeposited specimens. Yet the main mass of the Watton Bed is a hardened paper-shale—thin laminæ of very fine mud,—indicating a slowly-accumulating tranquil deposit. These statements appear to conflict: so does the statement about tranquillity with the observation that some ammonites are found more or less on edge, and that fairly large blocks of *Tetrarhynchia-thorncombiensis* Bed have been redeposited in the Watton Bed.

The reason for supposing that the forms of *striatulum* type are redeposited are the following:—At Bothenhampton J. F. Walker found *striatulum* forms in a brown bed, and a species of later date (*Ammonites germaini*) in white stone. The *striatulum* forms of the Watton Bed show evidence of a yellowish-brown matrix, although they are found in a very white lithographic stone. Associated with the *striatulum* forms are species of *Hammatoceras*—one form of the *H. insigne* type found in the rock itself and another (a rare and peculiar form somewhat removed from *insigne*, but certainly a *Hammatoceras*) was found on the lower platform loose: the matrix of the Watton Bed, however, is unmistakable. Now, *Hammatoceras* is of considerably later date than the *striatulum* forms, as may be seen from the synopsis on p. 401 (Table II). It is presumably of about the same date as the *Ammonites germaini* quoted by Walker, but is of pre-*Dumortieria* age. Therefore, the evidence appears to show that the forms of *striatulum* type which are found in Bed 4 are redeposited in strata of *Hammatoceras* date.

In the layer above, No. 3, is found evidence of a still later horizon, *Dumortieria*. The specimen belongs to a species with coarse, rather distant ribs, and is closely allied to *Dumortieria novata* S. Buckman (p. 387). But in this layer there is very plain evidence of redeposition apart from the *striatulum* forms: there is *Hildoceras* of *bifrons* type, which is a species some five hemeræ earlier than *striatulum* forms and some eleven hemeræ earlier than *Dumortieria*; and there are specimens of *Tetrarhynchia thorncombiensis*, which is some twenty hemeræ earlier than *striatulum* and some twenty-six earlier than *Dumortieria*.

It is evident, then, that the fossils which the Watton Bed yields are not to be trusted as evidence of the date of its deposition. And there is further evidence on this head in the finding of *Harpoceras* aff. *falciferum* (*mulgravium*) in the top of the bed (p. 388). Therefore, it is only possible to date the bed by the latest fossils which it contains.

What is, however, of considerable interest is the faunal inversion:—

Harpoceras at the top of the bed.
Hildoceras aff. *bifrons* in layer 3.
Grammoceras of *striatulum* type in layers 4 & 5.

This is an exact reversal of their true sequence. The possibility of such inversion had been already surmised from consideration of other cases.[1]

The important point is, however, that the evidence of ammonites is not to be trusted too implicitly in certain cases: it shows that special care has to be taken in reading records. That there was such an inversion might be explained on the supposition that, as the latest bed (that of *striatulum* date) was destroyed, its removal exposed an earlier bed (*bifrons*) which, in turn being removed, gave opportunity for the denudation of *falciferum*. But this is only a part of the history: it is fairly evident that strata of these dates and of others were all exposed to denudation at the same time. Thus *falciferum* contributed to the fauna of the lower part of one fallen block; *bifrons* (so far as the evidence of pink matrix goes) was laid under contribution for layer 9; *thorncombiensis* provided materials for layer 3, and for various earlier layers. While the middle and upper part of the bed was being laid down, however, a stratum which yielded *striatulum* forms was being considerably raided to provide materials, though it was not the only bed from which they were obtained.

The latest date for the deposition of the Watton Bed is determined by the date of the superimposed areno-argillaceous stratum (No. 13)[2]: the Watton Bed was laid down before that date. This sandy stratum is, from its position, presumably a less argillaceous representative of the Down-Cliff Clay which caps the Junction-Bed in the cliffs west of Eypesmouth; or it may be the equivalent of the basal part of the Bridport Sands, which in Burton Cliff assume a bluish colour in their lower part. But, again, these basal Bridport Sands may be really a less argillaceous condition of Down-Cliff Clay.

The Down-Cliff Clay has yielded *Dumortieria*,[3] the irony scale at the base of the Watton-Cliff sandy stratum has also yielded *Dumortieria*, the basal Bridport Sands at Burton have given no evidence. The Watton Bed is, therefore, earlier than the *Dumortieria* hemera, in the main. But an early form of *Dumortieria* occurs in the Watton Bed, layer 3; the irony scale which caps that bed and the complete lithic change between the Watton Bed and the sandy stratum point to a non-sequence of greater or less duration. It is to be concluded that the *Dumortieria* hemera contains really more episodes than our present time-scale allows for: first, an episode of early *Dumortieria*, during which calcareous conditions of lithographic-stone deposition obtained—a tranquil deposition of fine sediment resembling paper-shales; secondly, an episode of possible denudation while a lithic change was accomplished; thirdly, the episode of argillaceous or areno-argillaceous conditions of the Down-Cliff Clay and its equivalents, passing higher up into

[1] I, 9, p. 74, footnote 1.
[2] Section I, p. 382.
[3] I, 2, p. 519; I, 5, p. 64.

the completely arenaceous conditions of the middle part of the Bridport Sands. In this third episode *Dumortieria* ranges up some 60 feet in the Down-Cliff Clay,[1] and it may range as far again into the Bridport Sands before *Catulloceras* appears, while there is about 170 feet before evidence of *moorei* is obtained.[2]

The other supposition is that the upper part of the Watton Bed was deposited contemporaneously with the Down-Cliff Clay. This is possible, but it follows that a curiously limited horizontal extension of the lithographic-stone deposit in a westerly direction would have to be allowed, and, moreover, would have to be accounted for; because north-eastwards, so far as the Bothenhampton evidence goes, there is reason to suppose considerable horizontal range of lithographic-stone conditions.

On this theory the non-sequence between the Watton Bed and the sandy stratum might correspond to the time of deposition of the upper part of the Down-Cliff Clay.

So far, then, as our present time-scale allows, the three upper layers of the Watton Bed were deposited in the earliest part of the *Dumortieria* hemera. The layer below, which contains *Hammatoceras*, could be dated as *Hammatoceras* hemera, which precedes *Dumortieria*. The layer below (No. 5), which contains *striatulum* forms, can be dated as certainly later than *striatulum* hemera; but whether it can be dated as contemporaneous is a question for consideration later.

In this layer I obtained a reversed gastropod (*Cirrus*), thinking it to be a new record; but Moore has already figured and described[3] a similar form as *Turbo bertholeti* from the 'Upper Lias at Compton [near Sherborne, Dorset] . . . from the highest bed of that place in association with *Ammonites walcottii*.' There is reason to suppose at Compton and the neighbourhood a close association of *Grammoceras-striatulum* forms with *A. walcottii* [cf. *bifrons*], owing to paucity of sediment, erosion, or both; therefore the evidence is not necessarily against this gastropod being a contemporary of *striatulum* forms.[4]

The peculiar Hildoceratid ammonites of layer 6 have some resemblance to species which occur in the Jet-Rock of the Yorkshire Upper Lias (*exaratum* hemera), as, for instance, *Ammonites rugatulus* and *A. multifoliatus* Simpson; there is also likeness to *A. similis* Simpson, but this is perhaps from the *falciferum* horizon. The species of *Elegantuliceras*, *E. elegantulum* and *E. ovatulum* (Simpson), 'Yorkshire Type-Ammonites' ii, pls. xciii & cvi, may also be cited as similar, but they are thicker: they are from Jet-Rock, *exaratum* hemera.

[1] I, 5, p. 64. [2] I, 5, p. 64.

[3] VII, p. 210 & pl. vi, figs. 7–8.

[4] There is little doubt that, at Compton, Moore worked a higher (later) deposit of Upper Lias than at Ilminster. Analysis of his finds should show this. The forms common to Ilminster and Compton would presumably be from the lower bed; those peculiar to Compton might be expected to indicate the higher bed.

It is rather tempting to assign to the rock that date, because it would bring the *Thecidellæ* of the top of layer 7 into line with Moore's zone of *Thecidium rusticum* (p. 390). But there seem to be difficulties in this course:—(1) there is lithographic stone in layers 8 & 10 below; (2) there is pink rock suggestive of *bifrons* date in layer 9; and (3) the possibility that the *Harpoceras* aff. *mulgravium* found in a fallen block (p. 388) came from about the horizon of layer 8 or even below it.

The ammonites of layer 6 may have been derived, especially as Mr. Jackson has found similar peculiar Hildoceratid ammonites in far better condition nearly in the top of the bed (corresponding to layer 3, or possibly 4). His specimens are in quite unworn condition, showing no signs of derivation, yet it seems quite impossible to imagine that they were contemporaries of *Hammatoceras*—that is contrary to all our experience: there is admittedly a difficulty here. As to *Thecidellæ*, they can only have been derived if the whole slab to which they are attached had been derived. This is possible; but it is also possible that the *Thecidellæ* are a different species and of a different date from *Thecidella rustica*: they are too much weathered to make any determination of species satisfactory. And, even if such were made, our knowledge of the range of *Thecidellæ* is admittedly very incomplete: possibly several Whitbian horizons yield *Thecidellæ*, but there has been, since Moore's time, too little systematic search for them. The washing process, by which alone they can be obtained in satisfactory condition, is particularly tedious; and there are cases, as their occurrence in this calcareous Watton Bed shows, where it could be applied only with much difficulty.

If it be supposed that the peculiar Hildoceratids are *in situ* in the lower part, or not much removed from their original position, that they were at least deposited originally in a lithographic-stone matrix, then we are confronted with a difficult position, and the following theories may be put forward to account for the facts. A recapitulation of the facts may be helpful: they are:—

(1) A laminated lithographic-stone bed about $5\frac{1}{2}$ feet thick shows in the face of Watton Cliff, separating Yeovilian from Domerian sandy deposits.

(2) It is in the same position as the Junction-Bed of Down-Thorncombe Cliffs; but it is quite different in lithic character, and disagrees greatly in its fauna.

(3) The white-stone matrix runs through the bed, but there are other matrices mixed up with it.

(4) *Striatulum* forms occur in a yellowish matrix, but are redeposited in lithographic stone; they are associated with *Hammatoceras* and *Dumortieria*.

(5) There is faunal inversion.

(6) Certain small species of Hildoceratids of pre-*falciferum* aspect are found at two levels, towards the base and towards the top; those at the top are in the best condition and in a white-stone matrix.

(7) A white-stone matrix is not found in the Junction-Bed of the western cliffs; but it occurs at Bothenhampton and is post-*striatulum* in date.

These are the facts which have to be accounted for, and the following theories may be put forward :—

(1) The lithographic or white-stone matrix began to be deposited in pre-*falciferum* time, and its deposition continued until the time of early *Dumortieria*, although there were various breaks in the record due to penecontemporaneous erosions.

(2) The whole of the Watton Bed was laid down at about one date, *Hammatoceras* (that is, the base of the Watton Bed corresponds in date with the upper part of Walker's Bothenhampton section—it is post-*striatulum* wholly): therefore, it is altogether later in date than any part of the Junction-Bed of the Western Cliffs, and than all but the last layer of the Bothenhampton section. So far as agreement in lithic character is concerned, this would appear to be correct. So far as faunal contents are concerned, nothing that has been found lower than layer 4 is in favour of it.

(3) The Watton Bed consists of two similar deposits of rather widely different dates; there was a deposit of, say, pre-*falciferum* date which had the characters of white lithographic stone, and made up the lowest part of the bed, then there was a break, possibly with denudation, while *falciferum* and post-*falciferum* deposits were being laid down in surrounding areas, as for instance in that of Thorncombe; then followed a time of deposition at Watton Cliff, for which materials were obtained from *falciferum* and later deposits, from the pre-*falciferum* white-bed deposit, and even from the *thorncombiensis* rock. Afterwards came another period of definite lithographic-stone deposition beginning in *Hammatoceras* hemera (laid down not only at Watton Cliff, but at Bothenhampton), and continuing to the earliest part of the *Dumortieria* hemera. In other words, two deposits of similar character, but of widely different dates, have coalesced.

Let us consider these theories: the first theory carries various difficulties. That a homogeneous deposit existed for many hemeræ, and at the same time shows various non-sequences, is not a difficulty; for such a deposit, lasting through more than thirty hemeræ with various non-sequences, is illustrated in my last paper.[1] But the difficulty is to suppose that during all the long time of about eighteen hemeræ which the fauna of the Watton Bed would require for its deposition (that is, from pre-*falciferum* to early *Dumortieria*), the white-stone conditions had so remarkably restricted a geographical range—not extending to the cliffs west of Eypesmouth, about 7 furlongs westwards, where different conditions of deposit obtained, nor to Bothenhampton, about 2 miles away to the north-east, until the time of *Hammatoceras* hemera, when white-stone conditions did come in at that locality.

Next there is evidence that white-stone conditions were not really continuous. Some small Dactyloids are in a brownish

[1] I, 9, p. 100.

matrix, and the *Grammoceras-striatulum* forms are in a yellowish deposit.

The second theory requires that *Hammatoceras* or some contemporary should be found low in the Watton-Cliff Junction-Bed. This theory does not account for the white matrix of the presumed pre-*falciferum* Hildoceratids, found by Mr. Jackson towards the top of the bed. And it involves the following corollaries: (*a*) that any strata deposited in the Watton-Cliff locality during the making of the Junction-Bed of the Western Cliffs and elsewhere were broken up and redeposited during *Hammatoceras* time; (*b*) that all such strata were removed, and then that the *Hammatoceras* sea had access to exposed strata of *thorncombiensis*, pre-*exaratum*, *falciferum*, *bifrons*, *striatulum*, and other hemeræ, in order to gather materials for the making of the bed—to a certain extent layers 2, 3, & 4 give evidence that some portions of such strata were available for supplies; (*c*) that all the faunal contents of the Watton Bed which are of older date than *Hammatoceras* have been derived.

The third theory sounds rather elaborate, but it seems helpful in many ways: (*a*) it will account for the pre-*falciferum* Hildoceratids having a white-stone matrix, so that they have the same matrix after derivation as that in which they are enclosed; (*b*) it synchronizes this presumed pre-*exaratum* deposit of fine-grained lithographic stone with the paper-shales of North Gloucestershire—as, for instance, Alderton-Dumbleton: and such synchronization of two fine-grained, thinly-laminated deposits is rather an interesting point; (*c*) it accounts for the absence, except as derivatives, of deposits of post-*falciferum* to pre-*Hammatoceras* hemeræ, and also for their irregularity; (*d*) it brings into accord the commencement of the second white-stone deposit at Watton Cliff with the same deposit at Bothenhampton—there it is post-*striatulum*, presumably *Hammatoceras*; at Watton Cliff it is post-*striatulum* certainly *Hammatoceras*, so far as layer 4 is concerned.

If, however, this theory be correct, then there will be the following corollaries awaiting acceptance:—

(*a*) The presumed pre-*falciferum* Hildoceratids should be found in the basal part of the blocks: unfortunately, this basal part is the most difficult portion to attack; (*b*) this pre-*falciferum* white-stone deposit has been removed by denudation from the Junction-Bed of the Western Cliffs and of other places: there certainly is a non-sequence in the required position—both stratal and faunal failure; this is not asking too much, because denudation of the pre-*falciferum* deposits occurs over a considerable area—south of North Gloucestershire they are only preserved in patches, and in stratal sequence those are often incomplete; (*c*) that the main constituents of the Junction-Bed of the Western Cliffs were not deposited in the Watton Bed in a regular order, but are only represented by chance faunal and stratal elements in

disorder; (*d*) that the second white-stone deposit has practically come into contact with the first one, giving the Watton Bed a false appearance of stratal continuity, whereas it masks a considerable non-sequence—say, some dozen or more hemeræ; (*e*) that the second white-stone deposit which is of two dates at Watton Cliff—*Hammatoceras* and earliest *Dumortieria*—has been partly removed, so far as the *Dumortieria* portion is concerned, from Bothenhampton, and has been wholly removed from the Thorncombe area: there, indeed, removal has gone further—it has taken off the deposit of *striatulum* date from Thorncombe Beacon, and yet left it as witness for original deposition at the neighbouring Doghus and Down Cliffs, in places.

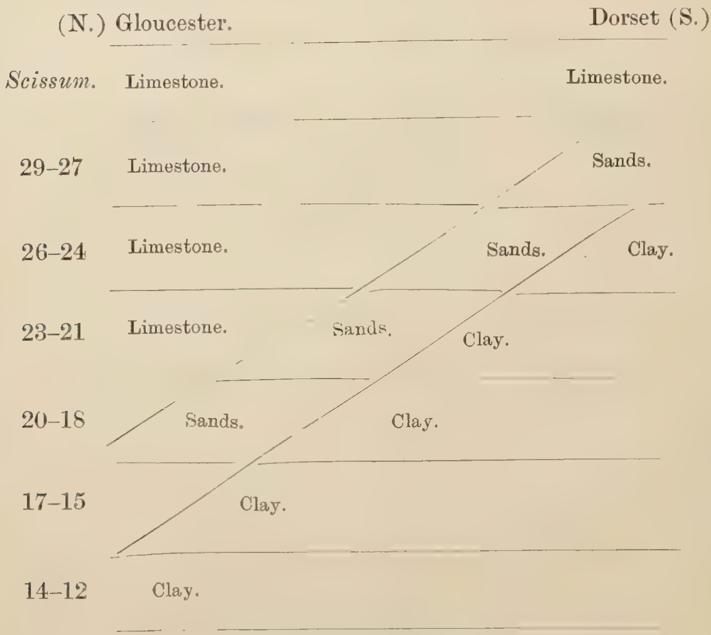
The phenomenon of what may be called stratal repetition—the occurrence of like deposits after greater or less intervals of interruption by deposition of strata unlike them—is quite well known. It occurs in two forms which may be called local and non-local—the first is stratal repetition in the same district, the second is stratal repetition, but not in the same district; there is stratal repetition in time, although what may be called the depositional focus has shifted. In the first case the like deposits are superimposed, in the second case they are not.

Those Jurassic sands of the South-West of England which makes a first appearance in Middle Lias (Domerian), and continue with various changes of locality until early Inferior Oolite (Aalenian), illustrate remarkably well stratal repetition, both local and non-local, as Table III (p. 415) will show.

Before illustrating this point I may say just a word about the so-called 'Midford Sands' or 'Oolite-Lias Sands' (Cotteswold, Midford, Yeovil, etc. Sands). From what one may read concerning lithological [lithic] evidence about change of deposit producing change of ammonite fauna, and when one sees assumptions made that the same formation stretching across country may be taken as evidence for the same date, I fear that the lessons to be gathered from the 'Midford Sands,' the secret of which I unravelled some years ago,[1] have not yet been learnt. Here is a formation of sand stretching across country for some 90 miles, from near Gloucester to the Dorset coast, resting upon clay below and capped by limestone rocks above. But the sand formation is not uniform in date—as it passes from north to south it gradually becomes later in time. Diagram 10 (p. 414) will illustrate this—the numbers refer to the hemeræ in Table III; but, of course, the diagram does not illustrate all the complexities due to differential thickening of deposits, to penecontemporaneous erosions, and so on. But it shows how unreliable a guide the lithic character may be. In this case clay, sand, and limestones are all being deposited synchronously during several hemeræ without, so far as is known, any effect on the ammonite faunas. But it can

[1] 'On the Cotteswold, Midford, & Yeovil Sands, &c.' Q. J. G. S. vol. xlv (1889) p. 440.

Diagram 10.—*Non-local stratal repetition.*



hardly be supposed that these simultaneous depositions of different strata form an isolated case—in fact, there is every reason to think that the phenomenon is rather frequent. It may, however, be masked by paucity of exposures and by hemeral sequences not having been so fully worked out. In the case of paucity of exposures, faunal analyses of the contents of a formation should be made. If they reveal notable discrepancies at certain localities, the explanation may be sought in the phenomenon of synchronous deposition of different strata—the similar lithic character as evidence of date should be regarded with suspicion.

It is not surprising that, in the Midford Sand case, observers disputed fruitlessly for many years as to the position of the Sands. But the palæontology of these observers was much at fault—a name like *Ammonites variabilis* was applied to species of such diverse genera as *Haugia*, *Phlyseogrammoceras*, *Pleydellia*, *Hammatoceras*, *Sonninia*, and *Fissilobiceras*.

I hope to be able to illustrate the phenomena of these Sands and synchronous deposits more fully in some subsequent paper of this series—much of it is written. Meanwhile, I return to the subject of stratal repetition, as illustrated by the geographical shifting of the focus of deposition (see Table III, p. 415).

TABLE III—DATES AND LOCALITIES OF SANDS.

Dates. Hemeræ.	Localities. Dorset Coast.	North Dorset.	Bruton.	Bath.	Sodbury.	Cottes-wolds.		
29. *venustula*	×						Bridport Sands.	Midford Sands *sensu lato.*
28. *digna*	×							
27. [*Cotteswoldia*] ...	×							
26. *moorei*	×	×					Yeovil Sands.	
25. *Catulloceras*	×	×						
24. *Dumortieria*	×	×						
23. *Hammatoceras* ...	...	...	×				Bruton Sands.	
22. *dispansum*							Midford Sands, *sensu stricto.*	
21. *struckmanni*	...	...	...	×				
20. *pedicum*								
19. *eseri*								
18. *striatulum*	...	...	...	...	×		Sodbury Sands.	
17. *variabilis*	...	...	...	...	...	×	Cotteswold Sands.	
16. *lilli*	...	...	...	...	...	×		
15. *braunianum*								
14. *fibulatum*								
13. *bifrons*								
12. *subcarinata*								
11. *pseudovatum*								
10. *falciferum*								
9. *exaratum*								
8. *tenuicostatum*								
7. *acutum*								
6. *athleticum*								
5. Harpoceratoid ...								
4. *spinatum*							Thorn-combe Sands.	
3. *thorncombiensis* ...	×							
2. *margaritatus* bed.								
1. pre-*margaritatus* bed	×	×	?	?	?	×	Down-Cliff Sands.	

So far as the Dorset coast is concerned, there are three sets of sands which are remarkably alike—so much so, in fact, that it is matter of common knowledge how difficult it is to be sure of the date (even in a general way) of a chance opening, especially as the strata are rather barren in a fossiliferous sense. The three sets of sands are those of pre-*margaritatus* bed (Down-Cliff Sands), separated by a thin calcareous and by a thin argillaceous bed from a post-*margaritatus* sand-deposit (*thorncombiensis*, the Thorncombe Sands), which is in some cases separated from the third

sandy deposit (Bridport Sands) only by the thin Junction-Bed. This is local stratal repetition. Non-local stratal repetition is illustrated by the other areas, which show the depositional focus of sands travelling northwards into Gloucestershire and then returning southwards to the Dorset coast again.

In Table III the interval between the Thorncombe Sands and the Bridport Sands seems to be very great, and so it is in the time-scale as well, if the full thickness of deposits made contemporaneously elsewhere were brought in—250 feet or so in *lilli-variabilis* hemeræ of the Cotteswold Sands alone; but in actual section on the Dorset coast the break is a very small matter, sometimes only about 2 or 3 feet—so little, indeed, that it may reasonably be inferred that the movements of the Weymouth Anticline have resulted in places in such small upheaval as was necessary to bring about the removal of the Junction-Bed and the superposition of Bridport Sands on Thorncombe Sands in one bed, with a wholly false appearance of sequence.

In argillaceous deposits stratal repetition is shown in Fuller's Earth, Upper Lias, Lower Lias—to name only a few. And in calcareous rocks the phenomenon occurs—certain strata of especially similar appearance may be named:—

Minchinhampton Stone (Great Oolite).

Notgrove Oolite.
Upper Freestone.
Lower Freestone.
Lower Limestone.
} Inferior Oolite.

These are strata of white freestone with oolitic grains: they are separated by deposits having other characters.

But to ask for a stratal repetition of a fine-grained white lithographic stone of two dates, one pre-*falciferum* and the other *Hammatoceras*, to be deposited in the same area so as to form one bed masking a non-sequence of considerable duration, is to make a somewhat extravagant demand, because of the great degree of similarity involved. There are two phenomena to consider—the first is repetition, and the second is coalescence. It will greatly strengthen the case to bring forward evidence of the first phenomenon in regard to lithographic stone, and of the second in regard to another stone; because, although the phenomena occur separately, there is obviously only one further step towards finding them occurring together.

Remarkable confirmation in regard to stratal repetition of a like deposit comes from a neighbouring place, Burton Bradstock [1]; there is found a white bed (which it will be necessary to discuss presently) of much later date, so similar to the white bed of Watton Cliff that, if portions without their fossils were mixed, separation could doubtfully be made. Now, the greater will include the less. Here is definite evidence that white-stone—lithographic-stone—conditions

[1] I, 5, p. 69.

recurred in the same area after the lapse of some fifteen to twenty hemeræ, so there is ground for surmising that the same phenomenon occurred at Watton Cliff after the lapse of some ten to fifteen hemeræ. But the two beds of presumed different dates at Watton Cliff have coalesced. Yet coalescence of unlike deposits separated by more than twenty hemeræ in time is well known; rarer, of necessity, is the coalescence of two like deposits of different dates, because the chances against it are greater: but it is known, and was commented upon in my last paper.[1] Possibly, other cases of such coalescence have been overlooked, because they were not understood. If only such coalescence of the Burton and Watton white beds had taken place, it would have provided a problem and a crop of ingenious surmises before it was understood. And there is just the possibility that such coalescence did occur—somewhere out to sea, in the neighbourhood of the axis of the Weymouth Anticline.

The third theory seems to have the greatest weight of probability in its favour; but, at present, that is all that can be said for it. If correct, it makes the Watton Bed contemporaneous, so far as its earliest part is concerned, with the pre-*falciferum* paper-shales of the North Gloucestershire Whitbian, and, so far as its later part is concerned, contemporaneous with the top layer of the Bothenhampton section, with the Yeovilian Sands of Cole, near Bruton (Somerset), and with the middle part of the Gloucestershire Cephalopod-Bed. It will be noticed that at present there is no ammonite evidence for any of the hemeræ between *Hammatoceras* and *striatulum* —in descending order: *dispansum*, *struckmanni*, *pedicum*, *eseri*. They have not been found at Bothenhampton nor in the Western Cliffs—at the former place towards the top of the Junction-Bed there is, consequently, a gap of four hemeræ; at Doghus and Down Cliffs, between the Junction-Bed and the overlying Down-Cliff Clay, there is a gap of five hemeræ; at Thorncombe Beacon there is a gap of six hemeræ. At Shoot's Lane, Symondsbury (Dorset), evidence for *eseri* has been found—*Haugia fascigera*[2] (now *Esericeras*).[3]

Stress has been laid on stratal repetition and coalescence, because this may possibly explain some of the Continental deposits which are puzzling, on account of inclusion in the same matrix of species of very widely different dates.

In the Red Ammonite-Limestone of Lombardy are species of various dates, from Domerian through Whitbian to Yeovilian, with certain notable omissions. The dates of the species are fairly obvious, and the deposit possibly represents a continuity of like conditions with erosions. But were the gaps—the portions

[1] I, 9, p. 86. [2] I, 5, p. 57.

[3] I, 8, pl. clxxxii. Since this was written, examination of Mr. Jackson's finds gives evidence for fauna of *eseri* and *pedicum* (or *struckmanni* hemera, perhaps) in the Western Cliffs. Such finds are always possible, and do not invalidate my statements; they stand good for many exposures of the Junction-Bed of the Western Cliffs.

unrepresented by fauna — filled by strata of like or of unlike character? There is no evidence.

The stratum of *Posidonomya alpina* of Sette Comuni (Italy) contains a fauna described and figured by Parona[1] which appears to show considerable mixture of Bajocian (and early Vesulian) with Callovian species. Parona notes that such an admixture has been recognized by E. Böse & H. Finkelstein for the same stratum in Southern Tyrol and by E. Jüssen for the Klaus Beds of the Northern Alps.[2] In Parona's case the admixture seems to be greater than he supposes, even allowing for the well-known and deceptive homœomorphy of certain Bajocian-Vesulian and Callovian species, and therefore the following remarks on some of his faunal elements may be of service. It is interesting to note how many of them have a distinctly Bajocian-Vesulian aspect. Before claiming them as Callovian species it would be very necessary to show that they, or very similar forms, occur in deposits which are unquestionably Callovian. If that could be done, then they would still remain of much interest, as illustrating heterochronous homœomorphy. But at present the majority of the forms about which the following notes are made appear to be strangers to Callovian, though not to Bajocian-Vesulian deposits.

Table IV—Remarks on Parona's Figured Species of Bajocian–Vesulian Aspect.

Reference.	Species.	Remarks.
Pl. I, fig. 11.	'*Oppelia subtilicostata*.'	Similar to Oppelids of *niortense* date.
12.	'*Œcotraustes minor*.'	Possibly a catamorph of *Cadomoceras*. Cf. *C. costatum*, I, 8, pl. clxxxix: *niortense*.
13.	'*Cadomoceras nepos*.'	Good evidence for *niortense* date.
14, 15.	'*Sphæroceras pilula*.'	Possibly catamorph of *Labyrinthoceras*, I, 8, pls. cxxxiv, cxxxv; c. *sauzei*.
16.	'*Sphæroceras auritum*.'	Like species of *blagdeni-niortense* dates.
17.	'*Sphæroceras? disputabile*.'	Like species of *niortense* date.
18.	'*Stephanoceras rotula*.'	Like the coronate stage of Perisphinctids of *niortense-truellei* date.
19.	'*Stephanoceras gibbum*.'	Very like *Trilobiticeras*, I, 8, pl. cxl; *Discites*.
21.	'*Stephanoceras venetum*.'	Remarkably similar to *Polyplectites* sp of the *truellei* bed of Burton Bradstock.
22.	'*Parkinsonia bonarellii*.'	Not a *Parkinsonia*, as the furcation is on the edge of the periphery; it should be about medio-lateral. A phaulomorph Perisphinctid; *truellei?*
Pl. II, fig. 1.	'*Cosmoceras pollux*.'	Like certain forms of *Strenoceras* of *niortense* date. But there is a great resemblance between the Bajocian–Vesulian genera *Strenoceras*, *Baculatoceras*, *Garantiana*, and the Callovian *Cosmoceras* in certain cases.

[1] VIII.

[2] VIII, p. 5.

Reference.	Species.	Remarks.
Pl. II, fig. 2.	'*Cosmoceras* n. f.'	Much like *Baculatoceras* of *niortense* date.
3.	'*Perisphinctes subtilis*' Neumayr.	Not *P. subtilis*. Very like *P. pseudomartinsii* Siemiradzki—*Prorsisphinctes*, I, 8, pl. cc; *garantiana*.
9.	'*Peltoceras chauvinianum*' A. d'Orbigny.	More like *Caumontisphinctes*, I, 8, pls. clxix & cxcii; *niortense*.
21–23.	'*Waldheimia bœhmi*.'	'Has the most remarkable likeness to *Waldheimia brodiei* S. Buckman (in Davidson, Mon. Brit. Jur. Brach. App. to Suppl., Palæont. Soc. 1884, p. 266 & pl. xix, figs. 14–15, which is a species from the Irony Bed (*blagdeni* zone) of Louse Hill.' [1]
24.	'*Waldheimia concava*.'	An anamorph of *Waldheimia haasi* S. Buckman in Davidson as above, p. 265 & pl. xix, fig. 12; *blagdeni* zone of Louse Hill.
19.	'*Waldheimia beneckei*.'	A catamorph of *Zeilleria ferruginea* S. Buckman, I, 4, p. 260 & pl. xiii, fig. 4; from the Irony Bed (*blagdeni* zone) of Louse Hill.

The stratum in question appears from Parona's description [2] to be homogeneous. It is making a rather large, though not impossible, demand on credulity to believe that this homogeneous deposit was persistent without alteration, through all the great number of hemeræ which are contained in Upper Inferior Oolite, Fuller's Earth, Stonesfield Slate, Great Oolite, Forest Marble, Cornbrash, Kellaways Rock to basal Oxford Clay. Continental authors, it is true, have failed to realize the great time-interval that exists between post-Bajocian and Callovian—being inclined to look upon them as merely a part of one deposit, because on the Continent so many of the stratal constituents are lacking. Quenstedt, for instance, placed such strata just in one division, Braun Jura ϵ, as if they all made up quite a minor episode. But I shall have more to say on that point in a sequel to this paper.

What concerns us now is the difficulty of thinking that the homogeneous deposit lasted persistently through all this time. There is perhaps no evidence against it in the shape of different deposits in the neighbourhood; but the great non-sequence suggests that a change of conditions occurred, that different deposits were laid down and were entirely swept away again—then that there was stratal repetition and coalescence.

The interesting point about the Burton White Bed and the Watton Bed is the definite evidence given for about 230 feet of strata, different from them and differing among themselves—sands and various limestones—separating two like deposits. But it is not difficult to picture another condition—a difference of geological and geographical history—sea where now is land, the

[1] I. 5, p. 105. [2] VIII, p. 3.

Dorset–Somerset evidence of these intervening strata swept away; land where now is sea, with coalescence instead of separation of the two White Beds. Then we might be examining a rock of white matrix obtained some miles off the Dorset coast which would puzzle us, because it showed in a homogeneous deposit Whitbian and Vesulian ammonites. Given sufficient destruction of evidence, and we might be long in arriving at the solution—erosion, stratal repetition, and then coalescence. Yet such, I think, is the explanation of sundry Continental deposits, and also of the Watton Bed itself: stratal repetition for the Yeovilian deposit and coalescence with a like Whitbian deposit—some of the intervening strata, of different lithic composition, being deposited in the Junction-Bed of the Western Cliffs and elsewhere.

The subject of stratal repetition and coalescence must receive further attention at another time.

IV. The White Bed of Burton Bradstock.

The likeness of the Watton Bed to that which I described as found at Burton Bradstock naturally attracted attention.[1] That bed is in Bridport Sands and also connected with faulting. Accordingly, in the autumn of 1919, I paid another visit to Burton. The first blow of the hammer fortunately hit a block disclosing examples of the same latesulcate '*Garantiana*' as that which I mentioned before.[2] It is not properly a 'Garantiana'; but it is a well-known form of the *niortense* bed of Louse Hill,[3] the *Astarte* or Rotten Bed[4] which lies above the Irony Bed. A fine-ribbed Perisphinctid was also obtained.

Subsequent labour, however, proved unproductive of more evidence for date. But a *Garantiana*-like form and a Perisphinctid in this bed are sufficient to show that, like as these two lithographic strata are in composition, yet they are of widely different dates—the Watton Bed is pre-Bridport Sands, the Burton Bed is on the border-line of Bajocian-Vesulian, not only post-Bridport Sands, but subsequent to the early and middle Inferior Oolite. What is interesting, however, is that the same fine muddy sedimentary conditions must have obtained at these two different dates: but, in the Burton case, it is only by the accident of faulting that a fragment of the later deposit has been preserved; in the Watton-Cliff case the accident of faulting has doubtless preserved the southern extension of the Bed, although that must be buried at a steep angle some 300 feet below Watton Cliff. What has been preserved is the unfaulted part which lies practically horizontal in the cliff-face, in position between Middle Lias and basal Bridport Sands.

[1] I, 5, p. 69. [2] I, 5, pp. 70–71.

[3] I, 5, p. 71. [The Louse-Hill species has, since this was written, been figured and named *Hlawiceras platyrrymum* (I, 8, pl. ccxl).]

[4] I, 3, p. 488, Section VI, Bed 3.

Mr. Linsdall Richardson has said that the Burton White Bed is *in situ* in Bridport Sands formed by percolation subsequently [1]; but while such an explanation might account for a deposit, it is quite inedaquate to account for the presence of fossils in that deposit. It seems hardly sufficient to account for such a deposit as this: percolation should produce calcite-veins (the so-called 'beef'), not a finely-laminated lithographic stone. The difficulty about the fossils in the deposit Mr. Richardson avoids by a suggestion which ignores my statements, and is totally at variance with the facts; he says:

'It was probably from this horizon [the top of the Red Beds] that the piece of "lithographic" stone came that yielded to Mr. Buckman fossils indicative of late *niortensis* or *garantianæ* hemera. Prof. S. H. Reynolds has very kindly examined microscopically one of the two pieces of "lithographic" stone that Mr. Buckman gave to the Director [Mr. Richardson]. These two particular pieces probably come from the top of the Red-Bed horizon.' [2]

My statements were

'The White Bed .... only occurs .... in the bank at the beach opposite the villas .... It is particularly exposed on the sort of pathway leading from the road to the beach, and just to the right hand as one reaches the beach.... The blocks on the beach were broken. The yield was several specimens [of fossils] .... and a piece of a *Garantiana* sp. nov.... known as a species from the *niortensis* beds of Louse Hill, near Sherborne.' [3]

The fossils and the rock-specimens were both obtained from the same place, from those blocks which are on the beach below the villas, blocks detached from the Bridport Sands, into which they have been faulted. The latest finds (1919)—similar ammonites, a Perisphinctid, and a *Nautilus*—were all extracted from the bank in the pathway below the villas.

Why Mr. Richardson made the assumption that the fossils and specimens came from the Red Bed it is difficult to imagine, especially as the cliff-section with the Red Bed is from a quarter to half a mile away; and I had remarked that [4]

'there is [in the cliff-section] practically no sign of any deposit of a thick white bed of the character of the one that has just been described.'

But the assumption was necessary to fit the percolation theory, in pursuance of which Mr. Richardson remarks that 'the lithographic stone might be found associated with fossils of any hemera.' [5] The difficulty here is that the fossils would show internally the different matrices formed during the hemeræ to which they rightly belonged. But these fossils from the white bed show inside and outside a white-bed matrix—they are evidently synchronous with the White Bed. Another objection is that the fossils of the White Bed are not found in any other of the Burton deposits. And there is a still further objection which may be taken to the percolation theory—that percolation would not produce a fine-grained, laminated lithographic stone.

[1] IX, 2, p. 56. [2] IX, 2, pp. 56–57. [3] I, 5, pp. 69–71.
[4] I, 5, p. 71. [5] IX, 2, p. 57.

It is now known that a similar lithographic stone was deposited horizontally and normally at an earlier date at Watton Cliff, of which the unfaulted part is preserved and the faulted part rendered inaccessible: it is reasonable to conclude that the Burton White Bed was deposited in a normal manner, but that the unfaulted part has been destroyed and only the faulted part preserved. A somewhat complicated series of events which involves faulting and penecontemporaneous erosion must be postulated, but nothing that is not already known in other cases.

Thus, in regard to the White Bed, there are the following facts:—

(i) That the White Bed is of later date than the Red Bed, and earlier than the *Astarte* Bed.

(ii) That the White Bed is not now found resting upon the Red Bed.

(iii) That the White Bed is not found separating the Red Bed from the *Astarte* Bed.

(iv) That the White Bed is a finely-stratified laminated deposit—in part, at any rate.

(v) That the White Bed is let down in a fault some 50 to 60 feet below the top of the Red Bed: that is, below its original position.

(vi) That it is mixed up with Bridport Sands.

(vii) That hard rocks of dates subsequent to that of the White Bed—that is, strata of the hemeræ *Garantiana* to *zigzag*—are not found associated with broken-up masses of the Red Bed.

Next, the following inferences may be drawn:—

(i) That the White Bed was deposited discontinuously on a surface of the Bridport Sands to the east, but with fair continuity on the surface of the Red Bed to the west.

(ii) That the White Bed is a deposit of slow accumulation, laid down under conditions similar to those of the lithographic stone of the Watton Bed.

(iii) That the White Bed deposited on the Bridport Sands must have been protected from the denuding agency.

(iv) That the preservation of the White Bed is apparently due to a small syncline in the Bridport Sands.

(v) That the White Bed was removed from the top of the Red Bed before the commencement of the deposition of the *Astarte* Bed.

(vi) That the hard rocks of the strata of hemeræ *Garantiana* to *zigzag* must have been either not deposited on the top of the White Bed of the Bridport-Sands tract, or, if deposited, they must have been completely removed again, otherwise they would be found associated with fallen blocks of the White Bed.

(vii) That non-deposition of these strata on the top of the White Bed would mean the elevation of the sand tract above the water, and would therefore expose it to denudation, which would bring about the total loss of the White Bed.

(viii) That deposition of these strata on the White Bed is a necessary supposition; but that this requires a postulate as to their subsequent removal.

(ix) That it is necessary to suppose that a soft rock easily yielding to denudation—a rock like the clays of the Fuller's Earth—was the immediate covering of the White Bed at the time when faulting occurred, as such a rock could easily disappear from the face of the White Bed without leaving any traces.

To account for these facts and inferences, the following history of events may be suggested. Diagram 11 (I–V), pp. 424–25, which illustrates the different events is merely a sketch, only approximately to scale. Vertical scales are, of course, greatly exaggerated in relation to horizontal:—

(i) Towards the end of the deposition of the Red Bed there was elevation of the tract of Bridport Sands on the east.

(ii) There was denudation of this tract, and then the White Bed was deposited on a surface consisting of Red Bed in the west, passing across strata down to Bridport Sands in the east (I in diagram 11).

(iii) Subsequent to the deposition of the White Bed, and before the deposition of the *Astarte* Bed, there was a renewed elevation of the Bridport Sands. Then there was denudation of the White Bed and its complete removal off the Red Bed, but its preservation in the Bridport-Sand area in a small fold east of the anticlinal axis (II in diagram 11).

(iv) Following this was the deposition of the *Astarte* to *zigzag* strata non-sequentially upon the various denuded surfaces (II).

(v) Renewed elevation of the Bridport-Sand tract came next, with a denudation which removed from that tract all the *zigzag* to *Astarte*-Bed strata and possibly some more of the White Bed; because the supposition that the later denudation should cease at the same place as the earlier makes too much demand upon coincidence (III in diagram 11).

(vi) On such a denuded area Fuller's Earth was deposited (III).

(vii) At some date subsequent to the deposition of the Fuller's Earth—perhaps at the same date as the faulting in Watton Cliff—the strata of the Bridport-Sand tract bearing the White Bed were let down considerably, and at as steep an angle as are the Junction-Bed and Fuller's Earth of the faults in Watton Cliff.

(viii) That the soft Fuller's Earth would be rapidly removed, and would then leave the White Bed exposed. IV (diagram 11) gives a view of this condition of affairs, in profile at right angles to the supposed fault-face, the elevation of the rocks inland being of course greatly exaggerated in relation to the horizontal scale, and V gives a picture of the same looking on to the fault-face, omitting the rocks which lie directly inland, but showing those of the cliff which lie to the westward. In this case it should be noted that really, from the fault westwards along the cliff to where the Fuller's Earth is preserved, is a distance of about half a mile.

(ix) While the White Bed was being eroded from the surface of the Red Bed, there is the possibility that portions of it may have been broken off and cemented on to the top of the Red Bed with ground-up paste of the Red Bed; and there is always the possibility that pockets of the White Bed may yet be found in hollows of the Red Bed. A recent discovery of a possible White-Bed block in the *Astarte* Bed will be noticed presently.

This theory of the course of events is, at any rate, superior to the percolation theory, in that it does not commence with an incorrect assumption as to the facts. The only real call that it makes on probability is in postulating two elevations and erosions, the second elevation being so adjusted that all the hard rocks of *Garantiana* to *zigzag* hemeræ are removed from the surface of the White Bed, but that some portion of the White Bed is left intact. Yet this is only asking for a phenomenon on a small scale, such as is exhibited on a large scale over a considerable area of the Cotteswolds. There the strata which intervene between those of *bradfordensis* and *Garantiana* hemeræ were deposited after a period of

Diagram 11.—*Presumed history of the White Bed of Burton Bradstock (Dorset).*

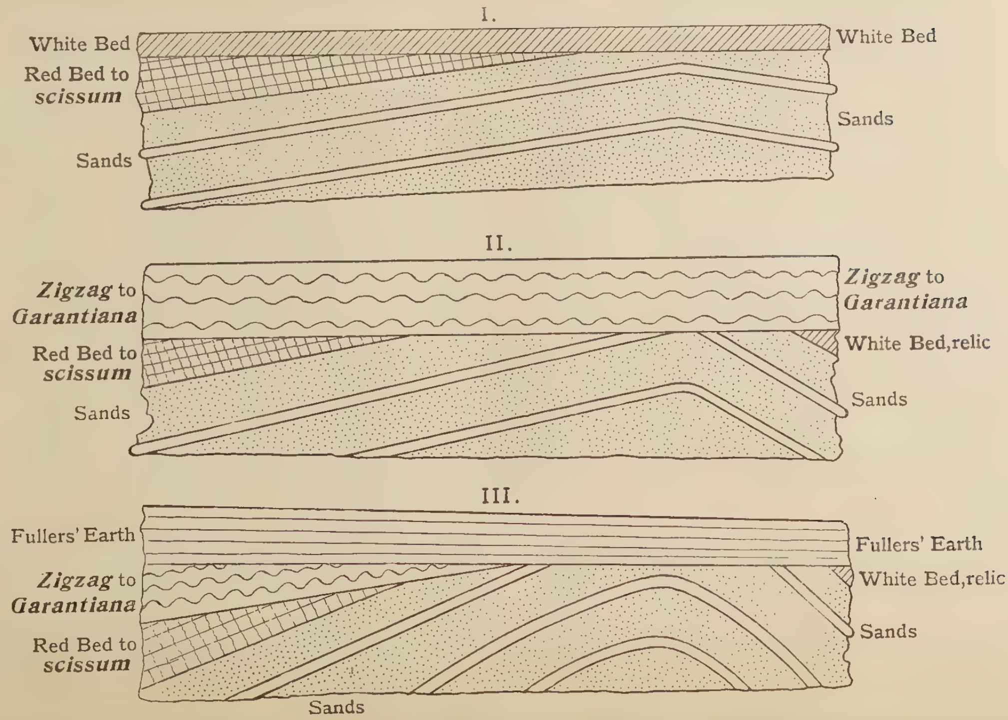
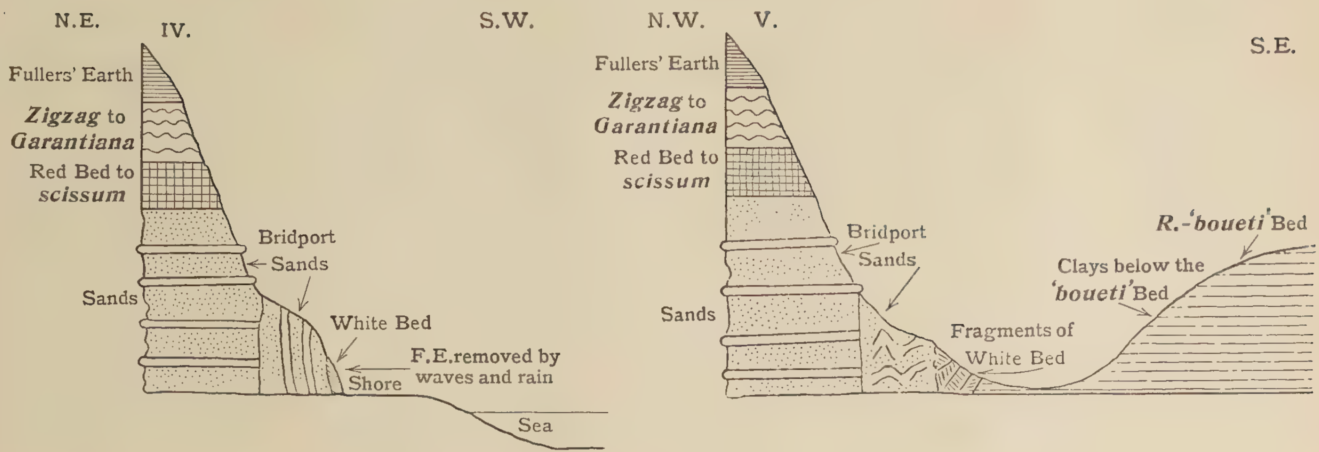


Diagram 11 (continued).



elevation and erosion, yet prior to another period of elevation and erosion. The second erosion obliterated all these intervening strata from certain places, yet was so adjusted that they were preserved in other places. But the latest bed of all is only preserved over a rather limited area—Cleeve Hill,—and strata which ought to follow on this bed, preceding those of *Garantiana* hemera, have been completely destroyed.

It is not necessary to assume that a fault was present until the date which let down the White Bed to its present position—long after Fuller's-Earth date presumably.[1] All that need be assumed is a gentle fold bringing Bridport Sands first to the level of the Red Bed, and then to the level of the *Zigzag* Bed: the actual anticlinal axis being about on the present line of fault, which would give a syncline just beyond it sufficient to let in the White Bed.

We do not know how thick the White Bed was originally. Say that there is now some 2 or 3 feet of it preserved. It may have been deposited to a thickness of 20 feet, of which only this small portion is preserved, and that by an accident. It is true that the other Inferior-Oolite rocks of Burton Bradstock are quite thin; but this is no measure of their original thickness—it is the result of the constant denudation that they underwent, being removed almost as fast as they were deposited. Some of them thicken considerably only a short distance inland—away from the axis of the Weymouth Anticline.

For instance, at Vetney (Vinney) Cross, which lies about 3 miles north-east by north of Burton Bradstock (or about 8 miles from the axis of the Weymouth Anticline), the *Garantiana* Bed is 18 inches thick as against 4 inches at Burton or an increase of $4\frac{1}{2}$ times, while the *truellei* bed is about 6 feet as against less than 2 feet at Burton; this, however, is not the full thickness, for really the deposit of 6 feet corresponds to about the lower 6 inches of the Burton *truellei* bed, or an increase of 12 times as much. Then at Nettlecomb, near Powerstock Station (about 5 miles north-north-east of Burton Bradstock), a rather poorly-fossiliferous quarry shows some 20 feet of *schlœnbachi* deposit, as against less than 5 feet at Burton; and yet there is no sign of the subjacent or superjacent beds, either in the quarry or in the stones of the fields around.

We speak of the sequence *blagdeni*, *niortense*, *Garantiana*; but we have no certainty that this is the complete sequence. It may be that, between the hemeræ *niortense* and *Garantiana*, strata were deposited of which no trace has yet been discovered.[2]

[1] The Forest Marble of Watton Cliff contains pebbles of a White-Bed matrix. It is an interesting speculation whether these have been derived from destruction of the Burton or from that of the Watton White Bed. They appear to be rather too soft for either; but this is a case where chemical analysis might yield some evidence.

[2] The most likely place in this country for such a discovery is near Sherborne (Dorset), in the neighbourhood of the quarries of Frogden and Lower Clatcombe. Seeing how little distance at Burton Bradstock is required to bring in a bed not found in the other neighbouring sections, there is no telling what an excavation at 100 or 200 yards in certain directions near Sherborne might not reveal. This subject may be more fully worked out in a later paper.

It is fairly certain that, when the fauna of the strata now dated as *niortense* are submitted to analysis, several episodes will be found covered by the one name—deposits of one episode have been preserved at one place, and those of others in other places. And yet the sequence may not be complete.

These remarks are made to show that, on theoretical grounds, there is reason to claim plenty of time between the dates of the deposition of the Red Bed and the *Astarte* Bed for the various events of elevation, denudation, deposition, to have occurred even in repetition. And there is actual evidence in support: in the Hebrides, according to the researches of Dr. G. W. Lee, some 70 feet of strata separate deposits which are respectively the equivalents of the Red Bed and the *Astarte* Bed. Unfortunately, they are unfossiliferous, and so their dating as *niortense* rests only on the fact that they are between *blagdeni* and *Garantiana* hemeræ. Then in the Sherborne district there are poorly fossiliferous strata—the Building-Stones—which are post-*niortense*: they are reckoned as belonging to the *Garantiana* hemera, and so is the *Astarte* Bed of Burton Bradstock; but that they are strictly contemporaneous is possibly doubtful—the various *Garantiana*-like forms in the two deposits show certain differences, and therefore, at any rate, the species are not altogether identical. Possibly the *Astarte* Bed is, in part at least, of somewhat earlier date than the Building-Stone of Sherborne; but it is unadvisable to speak positively on this point, until the *Garantiana*-like forms can be worked out in detail—a long task with such a mass of material as the strata yield.

The point to be emphasized is the necessity of knowing whether our chronological datum-lines are strictly contemporaneous; because, as it is only possible to estimate time by the amount of work performed during stated periods, it is necessary to be certain that the periods are identical. For instance, was the thickness of 70 feet in the Hebrides laid down only prior to the Building-Stone of Sherborne, or was it laid down prior to the *Astarte* Bed of Burton, or, as is possible, was it laid down even prior to the White Bed of Burton? These possible differences make considerable difference to the time-estimate; for, in the last case, the 70 feet represent work done in a time-interval between the Red Bed and the White Bed, which was a period of upheaval and erosion at Burton; then between the Red Bed and the *Astarte* Bed, which reposes upon it, one could place a time-interval represented by work done in depositing 70 feet in the Hebrides, and, in addition, an unknown original thickness of White Bed. It is rather interesting to note that the White Bed, which is the sole representative at Burton of the time-interval between the Red Bed and the *Astarte* Bed, should not be found separating them, and has only been preserved by an accident.

Bearing on the remarks about the possible original thickness of the White-Bed deposit, there is this to be said further: in the Sherborne district the pre-*Garantiana* zones of the Inferior

Oolite are thin deposits, averaging about a foot or so, but the *Garantiana* deposit is a thick one—running up to 40 or 50 feet, perhaps more. The paucity of fossils accounts for such horizons as there may be not being followed out in the different quarries of Building-Stone, for these quarries may be really on various levels—if so, the thickness would be much greater. Therefore, a surmise of a possible 20-foot deposit for the original White Bed is not necessarily a gross overestimate.

It is interesting to note that these lithographic-stone beds of the Yeovilian of Watton Cliff and of the late Bajocian of Burton Bradstock have a great likeness to the Continental strata termed White Jura, *diphya*-kalk or Alpenkalk, which form so conspicuous a feature of the Upper Jurassic over wide areas. It has, before now, been claimed for this country that its special geological interest lies in the fact that, small though its area be, yet it contains strata so fully representative as regards all the different dates and all the different structures. Yet it is correct, I think, to say that before the date of my discovery of the lithographic stone of Burton, it showed nothing to compare with strata laid down under those conditions which produced the Alpenkalk. Now, however, the Watton Cliff discovery adds another representative of such conditions—a deposit made at a still earlier date: so it is now unnecessary to travel outside England to obtain samples of strata like those of the Alpenkalk. And there will be this additional interest attached to them, that these beds of Watton Cliff and Burton indicate Alpenkalk conditions of deposition prevailing in Western Europe long prior to the date when they held good in Central Europe.[1] How long these conditions endured in the English cases, and what respective thicknesses of strata were laid down, can only be matters of surmise; for penecontemporaneous erosion has removed so much, and came near to removing all. How wide an area was occupied by such deposits is also matter for surmise—they may have spread far over the area now occupied by the English Channel. Some parts of the deposits may now lie buried beneath its waters, other parts of them have certainly been destroyed by those waters. Only a very few cubic yards of deposit in the Burton case are now left available for investigation. In the case of the earlier deposit, there may be a good deal more. There is certainly not much in Watton Hill itself: for the bed is cut off on the south by the Watton Fault, and on the west, north, and east by the landward slope. There is, perhaps, no more than an area of some 250 to 300 square yards preserved. But this White Bed has been detected in Shipton Long Lane, Bothenhampton—say, about three-quarters of a mile inland from the east-and-west line of Eype—and there is a possibility that it can be found farther inland, as around Allington Hill.

[1] Mr. J. W. Tutcher rightly draws my attention to the Sun-Bed in the White Lias of the Radstock-Bristol district as being an earlier deposit of similar character. Therefore in the South-West of England there was a threefold repetition of this kind of rock.

Now, Bothenhampton is some 7 miles from the main anticlinal axis of the Weymouth Anticline. If it be a legitimate surmise that the conditions producing Alpenkalk extended as far south of the axis of the anticline as they do north of it, then a north-to-south stretch of the White Bed was some 14 miles. To put the east-to-west stretch at the same distance would be reasonable: this would give nearly 200 square miles of area as the original extent of White-Bed deposit. To put the east-to-west stretch at some three times the distance would not be really so very unreasonable: this would imply some 600 square miles of area—by no means an inconsiderable extent.

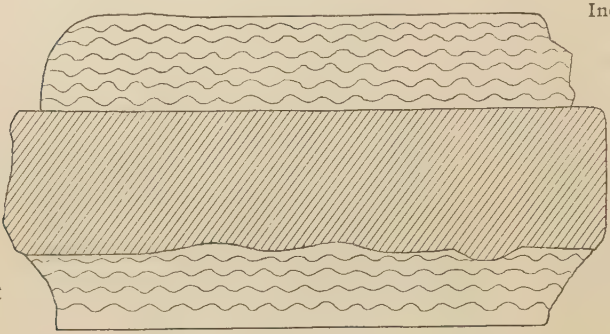
The exploration north of Bridport of what is marked as the contact-line between Lias Marlstone (G 2) and Lias Sand (G 4) would certainly be desirable, as giving a chance of finding further evidence of the Yeovilian White Bed. But there is little chance of exploration in such an area giving more evidence for the Burton White Bed, as there are plenty of quarries opened at the necessary horizon and they have received much attention. However large may have been the surface over which the Burton White Bed was deposited, it seems unfortunately to be only too true that it has been wholly removed from all that area. If such removal did not wholly take place, as at Burton Bradstock, prior to the deposition of the *Garantiana* Bed, it was accomplished later, when it shared the fate which in some localities was meted out to the *Garantiana* or subsequent deposits. But there is reason to suppose that the main accomplishment of its destruction was a pre-*Garantiana* episode, for, unlike the strata of *niortense* date which are preserved only at a few isolated localities, the strata of *Garantiana* date have a remarkably wide spread.

An observation made at the Black Rocks, west of West Bay, tends to confirm the theory that the White Bed was an original stratified deposit, broken up and redeposited later, where it was not preserved by being let down in the fault. At the Black Rocks, about the middle, close to the beach of pebbles, was found a big block (diagram 12, p. 430)—4 feet long, 18 inches broad and 26 inches thick—consisting of the *Astarte*-Bed (*Garantiana*) matrix, recognizable by its lithic characters and the great number of various fossils shown in section. About in its middle it carries a large mass (1 foot thick), extending rather beyond the length and breadth of the block, because of its superior hardness. This mass is a very compact, close-grained, grey rock, apparently quite unfossiliferous. It differs from all other local Inferior-Oolite rocks except the White Bed; that it resembles in texture, hardness, and paucity (if not absence) of fossils. In colour it differs somewhat, but not more, perhaps, than the difference of locality—it is nearly 2½ miles from the Burton White Bed—might explain. It certainly seems as if this included mass might be a local portion of the White or *Nautilus* Bed redeposited in the *Astarte* Bed. If such be the case, then, as the Black Rocks lie at the foot of Watton Cliff, we should have evidence of the second White Bed deposited in the same locality as the first.

Mr. Richardson says with regard to the Burton White Bed: 'the very white aspect of the stone was due to weathering of the surface.'[1] This is not my experience—the true lithographic stone is beautifully white, inside as well as outside.

The Black Rocks which lie out to sea immediately west of the first fault from West Bay, should repay investigation. Hitherto they seem to have been neglected; but this may be due to the fact that they are inaccessible, except during certain low tides. It was only during my last visit to Eype (1920) that I found them sufficiently uncovered for a short examination, which enabled me to collect certain specimens, indicative of the *Astarte*-Bed (*Garantiana*) of Burton Bradstock, from some masses well

Diagram 12.—*One of the Black Rocks (Dorset).*



A = Ironshot fossiliferous (*Garantiana*) rock.
B = Very hard, fine-grained grey rock (White Bed equivalent).
C = Ironshot, like the hard portion of the Vetney Cross *Astarte* Bed (*Garantiana*).

off shore, but just landward of the big rock. At my next visit at low tide these rocks were not accessible; but, nearer the beach and among the shingle of the beach, were found certain blocks which could be recognized as *scissum* bed, Red Bed, *schlœnbachi* and *zigzag* beds, besides the mass of *Astarte* Bed just mentioned. At certain states of the shingle these beds are buried; but, given favourable conditions of tide and shingle, the Black Rocks should yield a good harvest. However, heavy tools are a necessity.

To return for a moment to the *niortense* bed: there is reason to suppose that this bed was originally of wide geographical extent—possibly from the Hebrides to Italy and the Carpathians, certainly from Sherborne (Dorset) through France to Würtemberg. But, although it was originally deposited over so vast an area, the bed is now preserved only at a few widely-distant localities and is lacking from intermediate areas—much of it was wholly destroyed

[1] IX, 2, p. 56.

prior to the deposition of strata of the *Garantiana* hemera, much of what may have escaped that destruction perished in later erosions along with the whole of the Inferior Oolite. I have made a rough calculation that possibly not 1 part in 30,000 of the bed as originally deposited has been preserved. I do not pledge myself to the figures; they may be thought to be an under-estimate, but there is also reason to think that they may be an over-estimate. But to give an idea of what such destruction means: there are about 30,000 post-offices in the British Isles enumerated in the Postal Guide. If we were to destroy all these names but that of Sherborne (Dorset), we should thereby obtain a picture of the destruction of the *niortense* bed. Then consider how small a part a quarry or two forms of the preserved portion, and that, when such quarries are in work, many years may pass without anyone visiting them. On such a basis, it is easy to understand that the collected material may form no more than one part in a million of the entombed originals.

Which deposit of the Jurassic hemeræ has suffered the most in regard to destruction may be a matter for future research, but the *niortense* bed will, I expect, be one of those which make the greatest claim to such distinction. It is not proposed to enter into details on this subject here—the accumulation of evidence is no light task; but it is hoped to initiate in a sequel to this paper a geographical enquiry as to the original extent of the *niortense* bed and as to its present preservation, which may fit in suitably with some other geographical studies suggested by stratal and faunal phenomena of the rocks to be dealt with in that sequel.

V. Certain Chronological Studies.

(A) Milborne Wick and the Green-grained Marl.

In the Table[1] of his paper on the Doulting-Milborne-Port district, Mr. Linsdall Richardson places opposite *blagdeni* hemera, and under Milborne Wick, the following 'Marl with green grains, S. S. Buckman.' The placing of it within inverted commas makes it appear like a statement taken from my paper,[2] or given on my authority. But this is incorrect: reference to my section of Milborne Wick will show that I divided the beds in more detail than did Mr. Richardson. I recorded

Humphriesiani.	2. Soft white chalky limestone, 4 inches.
[*blagdeni*].	
	3. Grey limestone with iron grains, 6 inches.
sauzei.	4. White limestone, 6 inches.
	5. [Soft limestone] speckled with green grains. *Astarte spissa.*

Here I have said nothing about any green grains in the limestone of *blagdeni* hemera: at the top that is white, without coloured

[1] IX, 3, facing p. 518. [2] I, 3, p. 502.

grains, lower it has grains which are noticeably pink; at a still lower level, which I dated as *sauzei*, are the green grains.

The point is of considerable importance for dating specimens. In the 'seventies (at the time, I understand, when the road-cutting was made at Milborne Wick), very extensive collections of fossils were obtained from this place: many are in my collection, and it is rare to see a public or private collection without noting fossils which have the characteristic Milborne-Wick matrices. If my observations are correct, the lithic differences afford a means of ascertaining the sequence of these fossils. I have examined many ammonites in my collection, and they certainly tend to confirm this opinion. The very common fossil of the *blagdeni* zone is *Pœcilomorphus cycloides*—common, because the name really covers a multitude of different forms; but Mr. Richardson does not mention this species.

Not only is he incorrect in citing my authority for this dating of the marl with green grains; but I think that he may be incorrect in his dating of the beds which he saw. My 'Bed 2' is given by me as 4 inches thick, and Beds 3 & 4, as 1 foot, total = 16 inches. Mr. Richardson's Beds 2 to 4 total 13 inches. So on that basis he may have hit a place where Bed 2 was only 1 inch thick. But there is a lack of 14 inches in the rest of his section—under Bed 6. I think it possible that where he took his section he saw, at the top, Bed 5—where I noted the green grains—with just some small portions of the higher beds and their fossils in more or less derived condition mixed up with the disturbed green-grained marl. This point might be settled by an examination of the matrix inside the fossils, not that outside.

There are two further points for consideration:—

That in this section local removal of the beds below the non-sequence—Beds 2–4—is possible, with the corollary that, at favourable places, Bed 2 may be thicker than is recorded in my section; and that there may be local variation in the thickness of any of the beds. Therefore, if Mr. Richardson found green-grained rock at the top of the section, whereas I found it at 16 inches below, the explanation may be local thickening at the top of Bed 5 and/or local denudation.

One point I would add about this section, from examination of ammonites from old collections—specimens of *Witchellia* show a matrix with green grains and *Astarte spissa*; wherefore it is possible that the top of Bed 5 should be reckoned as *Witchellia* and not as *sauzei*, as it is in my paper.[1] Actually I cannot recollect any example of '*Ammonites sauzei*' *(Otoites)* from Milborne Wick. The species '*Sphæroceras perexpansum*' *(Labyrinthoceras)*[2] cited for Bed 4 may really indicate a somewhat different date. But whether just before or just after cannot be said yet: this is a matter possibly to be considered in future faunal analyses.

[1] I, 3, p. 503.
[2] I, 8, pt. 19, pls. cxxxiv & cxxxv.

(B) Haselbury and Hammatoceratids.

In his paper on the Crewkerne district[1] Mr. Linsdall Richardson reproduces W. H. Hudleston's profile[2] of the now disused quarry near the church of Haselbury. When he was preparing his paper he asked my opinion as to the possible date of Bed 3: at that time I could only suggest *bradfordensis* hemera, adding, however, that I did not recollect any *bradfordensis* specimens from Haselbury. Since then the possible solution of the date has occurred to me. The keeled ammonites which Hudleston mentions from this Bed 3 are perhaps represented by the species of *Hammatoceras* and *Erycites*, which have been obtained from Haselbury and the immediate neighbourhood —*H.* cf. *planinsigne* Vacek and *Erycites* aff. *gonionotum* (Benecke): similar forms have been figured by Vacek[3] & De Gregorio[4] from the strata at Cape San Vigilio, Lago di Garda (Italy).

In the Bradford-Abbas district occur many species of these two genera[5]: they have come from strata mainly dated as *murchisonæ* hemera, though partly or occasionally as *bradfordensis*. But, when faunal analysis comes to be applied, it is seen that the synchronization of such species with *murchisonæ* (that is, the Ludwigoids), on the one hand, or with *bradfordensis* (that is, *Brasilia* spp.), on the other, becomes rather doubtful. At the Italian locality are few or no species that can be properly reckoned as either Ludwigoids[6] or *Brasilia*, but Hammatoceratids are abundant. In the Hebrides the Ludwigoids are especially abundant, but the Hammatoceratids are unknown. In Dorset-Somerset Ludwigoids associated with the characteristic brachiopod, the so-called *Waldheimia anglica*, are of fairly wide distribution and not uncommon, but Hammatoceratids are localized and particularly rare. At Haselbury both Ludwigoids and Hammatocerata are rare, for the quarry was not a productive one so far as ammonites are concerned; but Hudleston notices for Bed 4 *Ammonites murchisonæ* and *Waldheimia anglica*, and for Bed 3 he records keeled ammonites: evidently they were unfamiliar to him —had they been of *murchisonæ* or *concavus* (that is, *bradfordensis*) type,

[1] IX, 4, p. 165.
[2] VI, p. 41.
[3] XI.
[4] IV.
[5] I, 1, p. 661.

[6] So far as the Ludwigoids are concerned, this statement may seem particularly rash, for De Gregorio says (IV, p. 11) 'L'*Harpoceras Murchisonæ* est très-commun à S. Vigilio, et c'est une des espèces les plus caractéristiques de cette faune.' This illustrates the necessity for precision in palæontological identification. The specimens which he figures (IV, pl. iii) as *Harpoceras murchisonæ* with various qualifying terms show no species agreeing strictly with *Ammonites murchisonæ* itself, possibly no Ludwigoids at all, certainly not the *murchisonæ* fauna of the Hebrides nor of Dorset-Somerset, nor of other areas; while the list of species of widely different dates which he gives as possible varieties or mutations of *A. murchisonæ* show how greatly outward similarity may mislead. His *Harpoceras murchisonæ* includes a variety of types, some indicative of *Ancolioceras* date and perhaps of earlier hemeræ, some more or less suggestive of *bradfordensis* date, some perchance indicative of strata of even later dates.

it may be presumed that he would have appended some less general term.

On the assumption that at Haselbury the *Hammatocerata* occupy a higher bed, and are of later date than the Ludwigoids, which would lead to a theory of a Hammatocerate-Erycite horizon as distinct, that is, of later date than that of Ludwigoids, the facts of distribution could be explained. In Italy strata of *murchisonæ* hemera are absent or only represented in part, but those of a Hammatocerate-Erycite hemera are present. In the Hebrides, the former was very conspicuous, but there is as yet no evidence for the latter. In Dorset–Somerset the strata of the *murchisonæ* hemera are developed over a wide area; but those of the Hammatocerate date are wholly destroyed in some places, and partly removed in others. At Haselbury a bed assumed to be that of Hammatocerate date is preserved in sufficient thickness to attract attention as a deposit superior to that yielding '*Ammonites murchisonæ*.'

More analysis on these ines may suitably come later, and will be of greater value if and when some of the species of Hammatocerates can be figured. But, meanwhile, it may be advisable to consider the possibility of a Hammatocerate-Erycite date, as intermediate between those of *murchisonæ* and *bradfordensis*, and to date Bed 3 of Haselbury in Hudleston's (and Mr. Richardson's) communications as Hammatocerate-Erycite? rather than as '*bradfordensis?*'

The Cotteswold evidence seems in favour of this view. There between the Pea Grit (*murchisonæ* hemera) and Oolite Marl (*bradfordensis*) is a thick mass of poorly fossiliferous, perhaps non-ammonitiferous freestone with a more or less eroded surface: this deposit, in part at any rate, and the subsequent erosion (prior to *bradfordensis*) would mark the time required for laying down a Hammatocerate-Erycite stratum in other areas.

A short record of the chronological succession and geographical occurrences of some of the principal Hammatoceratid forms shows the faunal repetition and the limited extent—in some areas—over which the particular strata have been preserved: it is the earliest of these horizons that has come so much into discussion in connexion with the Watton Bed (see p. 387).

TABLE V—HAMMATOCERATIDS: CHRONOLOGICAL SUCCESSION AND GEOGRAPHICAL OCCURRENCE.

——— Intervening hemeræ omitted.

Hemeræ.	Fauna and Localities.
Eudmetoceras. [*discites/concava*].	*Eudmetoceras* spp.[1], *Euaptetoceras*.[1] Bradford Abbas district; Beaminster district (Dorset); Lago di Garda (Italy).
———	
'Hammatocerate'-Erycite. [*bradfordensis/murchisonæ*].	'*Hammatoceras*,' *Erycites*, *Abbasites*,[2] *Ambersites*.[3] Dorset and Somerset; Normandy; Lago di Garda; Lombardy (Italy); Monte Grappa (Italy); Bakony (Hungary).
———	

[1] I, 8, pls. clxxix, clxxx, ccxcix. [2] I, 8, pl. ccxxxvi. [3] I, 8, pl. ccxxxvii.

Hemeræ.	Fauna and Localities.
scissum.	*Bredyia* spp.
[*Ancolioceras*/*opaliniforme*].	Burton Bradstock (Dorset); Cotteswolds (Gloucestershire) in the Sandy Ferruginous Limestone; Normandy; Rhone Basin?
Hammatoceras (*insigne*). [*Dumortieria*/*dispansum*].	Watton Cliff, Eype (Dorset), Junction-Bed; Cole (Somerset), Bruton Sands; Cotteswolds, Cephalopod Bed; widespread on the Continent.

VI. A Palæontological Note—*Tetrarhynchia thorncombiensis*, nom. nov.

J. F. Walker identified specimens of this characteristic fossil from the Thorncombe bed as his *Rhynchonella northamptonensis*, and it is presumably the same form from the same deposit at North Allington, near Bridport, that he called '*Rhynchonella tetrahedra*, var. *northamptonensis*.'[1] But the Thorncombe form certainly is not the same species as that from Northamptonshire,[2] for that has clean-cut, sharp ribs; whereas the Thorncombe fossil has blunt, somewhat rounded-off ribs, and has a general smoothed-off appearance. As the two forms are certainly not contemporaries, as the Thorncombe fossil marks a particularly distinctive horizon on the Dorset coast, and as it has been frequently necessary to cite the name, it seems preferable to give it a distinct appellation rather than to perpetuate one which will require changing. I have selected a type to be figured in the proposed palæontological sequel to this paper, where it is also hoped to figure and describe various ammonites and brachiopods, which have special bearing on the chronology of Lias-Oolite rocks as well as giving evidence for widespread deposition of certain deposits.

VII. Bibliography.

I, 1. Buckman, S. S. 'The Descent of *Sonninia* & *Hammatoceras*' Q. J. G. S. vol. xlv (1889) p. 651.

2. Do. 'On the So-called "Upper-Lias Clay" of Down Cliffs' Q. J. G. S. vol. xlvi (1890) p. 518.

3. Do. 'The Bajocian of the Sherborne District: its Relation to Subjacent & Superjacent Strata' Q. J. G. S. vol. xlix (1893) p. 479.

4. Do. 'Homœomorphy among Jurassic Brachiopoda' Proc. Cotteswold Nat. Field-Club, vol. xiii, pt. 4 (1901) p. 231.

5. Do. 'Certain Jurassic (Lias-Oolite) Strata of South Dorset, & their Correlation' Q. J. G. S. vol. lxvi (1910) p. 52.

6. Do. 'The Brachiopoda of the Namyau Beds, Northern Shan States (Burma)' Palæontologia Indica, n. s. vol. iii, No. 2, 1917.

7. Do. 'Jurassic Chronology: I—Lias' Q. J. G. S. vol. lxxiii (1917–18) p. 257.

8. Do. 'Type-Ammonites' III & IV, 1919–22.

9. Do. 'Jurassic Chronology: I—Lias: Supplement 1, West England Strata' Q. J. G. S. vol. lxxvi (1920) p. 62.

II. Davidson, Thomas. 'Monograph of the British Fossil Brachiopoda' (Pal. Soc.) iv, pt. ii, no. 1, Suppl. to the Jurassic & Triassic Species, 1876; no. 2, 1878: Appendix to Suppl., 1884.

[1] XII, p. 438.

[2] II, 1878, p. 199, Suppl. pl. xxix, figs. 7–12: fig. 7 may be taken as lectotype of the species.

III. Day, E. C. H. 'On the Middle & Upper Lias of the Dorsetshire Coast' Q. J. G. S. vol. xix (1863) p. 278.
IV. De Gregorio, A. 'Monographie des Fossiles de S. Vigilio' Ann. Géol. Pal. livr. 5, 1886.
V. Eudes-Deslongchamps, E. F. G. 'Études sur les Étages Jurassiques inférieurs de la Normandie' 1864.
VI. Hudleston, W. H. 'A Monograph of the British Jurassic Gasteropoda: Part I—Gasteropoda of the Inferior Oolite' (Pal. Soc.) 1887–1896.
VII. Moore, Charles. 'On the Middle & Upper Lias of the South-West of England' Proc. Somerset Arch. Soc. vol. xiii (1867) p. 119.
VIII. Parona, C. F. 'Nuove Osservazioni sopra la Fauna & l'Età degli Strati con *Posidonomya alpina* nei Sette Comuni' Palæont. Italica, vol. i (1895) p. 1.
IX, 1. Richardson, L. 'A Handbook to the Geology of Cheltenham & Neighbourhood' 1904.
2. Do. 'Report of an Excursion to Bridport, Beaminster, & Crewkerne' Proc. Geol. Assoc. vol. xxvi (1915) p. 47.
3. Do. 'The Inferior Oolite & Contiguous Deposits of the Doulting-Milborne Port District (Somerset)' Q. J. G. S. vol. lxxi (1915–16) p. 473.
4. Do. 'The Inferior Oolite & Contiguous Deposits of the Crewkerne District (Somerset)' Q. J. G. S. vol. lxxiv (1918–19) p. 145.
X. Strickland, H. E., & Buckman, J. 'Outline of the Geology of the Neighbourhood of Cheltenham, by R. I. Murchison' new ed. 1844.
XI. Vacek, M. 'Fauna der Oolithe von Cap San Vigilio, &c.' Abhandl. K. K. Geol. Reichsanst. vol. xii (1886) p. 57.
XII. Walker, J. F. 'On Liassic Sections near Bridport (Dorsetshire)' Geol. Mag. 1892, p. 437.
XIII. Witchell, E. 'The Geology of Stroud & the Area drained by the Frome' 1882.
XIV. Woodward, H. B. 'The Jurassic Rocks of Britain: vol. iii, The Lias of England & Wales' Mem. Geol. Surv. 1893.

VIII. Appendices.

Appendix I—Sections of the Junction-Bed and Contiguous Deposits. By James Frederick Jackson.

[In brackets remarks on ammonites and brachiopods, by S. S. Buckman.]

(1) Introduction.

My acquaintance with the Junction-Bed dates from 1912; and, in the course of a number of visits to the sections between that date and 1920, several interesting facts bearing on the stratigraphy and palæontology of the bed have come under observation. Some of these facts appear to be new, and others, while not strictly new, have proved to possess a greater significance than had previously been recognized.

(2) Characters of the Junction-Bed (Western Cliffs).

In 1910 Mr. Buckman[1] recognized six separate layers in the Junction-Bed, and referred them to the hemeræ *striatulum*, *lilli (?)*, *bifrons*, *falciferum*, and *spinatum*. Day's '*Pleurotomaria* Bed' was not certainly identified. I have now noted, in addition to the above subdivisions: (i) a lenticular development of clay (O) between the *falciferum* and *spinatum* layers at Down Cliffs;

[1] 'Certain Jurassic (Lias-Oolite) Strata of South Dorset, & their Correlation' Q. J. G. S. vol. lxvi (1910) pp. 57 *et seqq.*

(ii) a thin ferruginous layer (N) with *Harpoceratoides* spp. below the limestones of the *falciferum* layer at Thorncombe Beacon; and (iii) a marly layer (N_1) at the top of the *serrata* bed, also at Thorncombe Beacon.

The blue sandy 'Upper Lias' clays everywhere rest non-sequentially upon the limestones of the Junction-Bed with a remarkably sharp line of division; and, owing to the impersistence of the several layers of the Junction-Bed, the clays may rest upon any layer from the *striatulum* to the *falciferum* zone. Usually, the basal 6 to 12 inches of the clays become more sandy and ferruginous than the main mass above, and this lower portion contains a good many coarse-ribbed *Dumortieriæ* in the condition of friable casts—mostly too rotten to be preserved. A long slender *Belemnites* sp. occurs, but is uncommon.

The lithic character of the *striatulum* layer varies much. In parts it is a hard, rubbly, greyish-yellow limestone; in other sections it is a soft earthy marl, with harder lumps and many limonitic nodules and rolled fossils in a perished condition. At the base is a very thin, impersistent seam of dense laminated limestone showing an obscure mammillated structure, suggestive of 'Cotham Marble.' Whenever the top of the *striatulum* layer can be examined *in situ*, it supplies plain evidence of long-continued quiet erosion, prior to the deposition of the 'Upper Liassic' clays, being planed off perfectly level and displaying ammonites in section—the lower or embedded side well preserved, the upper removed by the erosion. From a fallen block below Down Cliff I collected a large alticarinate *Haugia*, 5322[1] [*Esericeras* aff. *eseri* (Oppel), more umbilicate], almost as accurately cut through as if sliced on a lapidary's wheel: the erosion has removed the shell down to within a few millimetres of the thin high keel almost equally around the greater portion of the circumference of the shell. The *striatulum* layer reposes upon the smoothed top of the *bifrons* layer with a well-marked plane of division, but in perfect conformity. There is no obvious indication of the extensive non-sequence known to exist—a good illustration of the kind of deceptive conformity that has led to so many under-estimates of the importance and real time-value of attenuated deposits.

The *bifrons* layer is a hard tough limestone, usually mottled pinkish-yellow and red. Sometimes the stone is wholly fine-grained and massive; generally it abounds in pebbles of a similar rock, together with derived *Hildoceras bifrons*.[2] The derived ammonites are often reduced to mere limonitic pebbles showing traces of the sutures, etc. Unworn examples of *H. bifrons* occur among the redeposited specimens. The upper 2 or 3 inches of the *bifrons* layer is a greyish-yellow rubbly limestone, abounding in small specimens of *H.* aff. *bifrons* and *Dactylioceras* cf. *commune*;

[1] These numerals refer to my register of specimens.
[2] Trivial names of species are used *sensu lato*.

two or three species of small, thick-ribbed, involute Dactyloids are not uncommon. The *bifrons* layer is separated into two or three minor seams by impersistent planes of erosion, and occasionally the ammonites subjacent to these planes are in a similar condition to those at the top of the *striatulum* layer. Some of the ammonites are embedded in a vertical or highly inclined position, and in one or two instances which came under my observation the ammonite was seen to be truncated by a plane of erosion: a portion having been removed while the remainder continued firmly fixed in the rock, which must have been completely consolidated previous to the erosion. The division between the *bifrons* and *falciferum* layers is often rather obscure, and falsely suggestive of a passage.

The *falciferum* layer is a very hard tough limestone of a yellowish-pink colour, often mottled with red blotches; occasionally it is rather greenish. Sometimes the rock is fine-grained and compact; more often it is highly conglomeratic, containing broken and rolled *Harpocerata* and pebbles of a similar limestone. As in the *bifrons* layer, there are minor layers separated by planes of erosion. Apart from *Harpoceras falciferum*, fossils are uncommon, and all are very difficult to extract on account of the intense hardness of the stone.

The *falciferum* layer frequently rests directly upon a planed-off surface of 'marlstone,' but in places it appears to be transitional from a thin, earthy, ferruginous seam with *Pleurotomariæ* and other gastropods—presumably the '*Pleurotomaria* Bed' of Day.[1]

That writer's description is so vague that it is difficult to determine whether he considered the '*Pleurotomaria* Bed' to be a separate layer at the base of the 'Upper Lias' limestones, or merely the highest portion of the 'marlstone.' Mr. Buckman has observed an impersistent seam with nests of *Pleurotomariæ* at the top of the lower or *spinatum* layer of 'marlstone,' which he considers to be the true '*Pleurotomaria* Bed.' I have not noticed any very definite '*Pleurotomaria* Bed,' although *Pleurotomariæ* are fairly common in the *serrata* bed and rare in the main mass of the lower or *spinatum* layer. It is, perhaps, doubtful whether there is any particular horizon especially entitled to the term '*Pleurotomaria* Bed.'

At Down Cliff a lenticular deposit of clay intervenes between the *falciferum* layer and the 'marlstone'; but, since no fossils were obtained, it is impossible to say anything as to the exact date of this clay-band. The occurrence of a lenticle of clay within the Junction-Bed is noteworthy.

The *spinatum* layer or 'marlstone,' when fully developed, is divisible into two seams. The upper, Mr. Buckman's *serrata* bed, is usually a fine-grained oolitic limestone with a rich assemblage of well-preserved fossils: occasionally it is conglomeratic. The

[1] 'On the Middle & Upper Lias of the Dorsetshire Coast' Q. J. G. S. vol. xix (1863) p. 288.

lower portion of the 'marlstone' is a harder and much coarser rock, and is often highly conglomeratic. Most of the pebbles are made up of a similar coarse 'marlstone'; but pieces of a compact blue limestone and micaceous sandstone occur. Many large flat pebbles are thickly encrusted with a small *Serpula* and riddled by *Lithophagus* borings, the shells sometimes remaining in the crypts. There does not appear to be any definite line of division between the two layers of 'marlstone.' The base of the 'marlstone' is always highly irregular, on account of the presence of large branching and tuberous concretions of calcareous micaceous sandstone. The 'marlstone' rests upon an impersistent stratum of blue sandy clay, or directly upon the underlying Yellow Sands.

(3) Details of Sections (Western Cliffs).

I think that it will be convenient to describe the sections from Down Cliff to Thorncombe Beacon before dealing with the exposure at Watton Cliff, east of Eypesmouth, which exhibits so remarkably abnormal a facies as to call for special consideration.

The following scheme of lettering of the several layers of the Junction-Bed and the contiguous deposits will be utilized throughout the sections to be described below :—

Scheme of Lettering.

Dumortieria	A.	*lilli (?)*	K.
	B.	*bifrons*	L.
	C.	*falciferum*	M.
Hammatoceras	D.	pre-*falciferum*	N.
dispansum	E.	clay within Junction-Bed	O.
struckmanni	F.	*serrata*	P.
pedicum	G.	*Pleurotomaria (?)*	Q.
eseri	H.	*spinatum*	R.
striatulum	I.	clay below Junction-Bed	S.
variabilis	J.	yellow sands	T.
thorncombiensis	U.		

Section I—The Junction-Bed and Contiguous Deposits, measured *in situ* near the Western End of Down Cliff.

Hemeræ.	Strata and Fauna.	Feet	inches.
Dumortieriæ.	A + B. Blue sandy 'Upper Lias' clay. Coarse-ribbed *Dumortieriæ*.		
	Impersistent irony scale.	0	$0\frac{1}{2}$
Lilli ?—Bifrons.	K + L. Pale conglomeratic limestone, with a very smooth top.	0	2
	Hildoceras bifrons, Dactylioceras cf. *commune, Rhynchonella*. [5217, a fissicostate Rhynchonellid, gen. et sp. nov.; 5211 *a*, *Stolmorhynchia* cf. *bothenhamptonensis* (Walker); 5211 *b*, *St.* cf. *bouchardi* (Davidson), but with too strong a fold.]	0	9
	Faintly-marked parting.		
Falciferum.	M. Yellowish limestone with red blotches. *Harpoceras falciferum, Dactylioceras* sp.	0	7–8
Spinatum.	R. Oolitic conglomeratic 'marlstone,' with a very smooth top. *Belemnites* spp., *Pseudopecten æquivalvis*.	0	6–9
	T. Soft, yellowish, clayey sands.		

On the coast the westernmost exposure of the Junction-Bed is near the western end of Down Cliff, where the *falciferum* layer rests directly upon the 'marlstone.' A few yards east of this first exposure a clay-band comes in between these layers, and continues almost to the eastern extremity of Down Cliff, where it passes into a band of earthy marly stone. Section I shows the sequence near the western end of Down Cliff.

Section II shows the sequence near the eastern end of Down Cliff. Here the *striatulum* layer is present, and the inter-*falciferum-spinatum* clay-band reaches its maximum thickness.

SECTION II—THE JUNCTION-BED AND CONTIGUOUS DEPOSITS, MEASURED *in situ* NEAR THE EASTERN END OF DOWN CLIFF.

Hemeræ.		Strata and Fauna.	*Feet*	*inches.*
Dumortieriæ.	A.	Blue, sandy, 'Upper Lias' clay. Coarse-ribbed *Dumortieriæ* in friable condition; *Belemnites* sp.		
		Transitional from		
	B.	Yellowish sandy clay with ferruginous streaks.	1	0
Striatulum. [Traces of *pedicum* and *eseri* faunas].	I [G + H].	Grey earthy limestone, with many rotten limonitic nodules and rolled fossils. *Grammoceras* spp. common. Top planed off very smooth.	0	2
		[5317, *Grammoceras* aff. *audax* S. B.; 4989, *G.* aff. *comptum* Haug; 5320 *a*, *G. penestriatulum* S. B.; 5319, *G.* aff. *penestriatulum* S. B.; 5315, 5318, *G.* aff. *penestriatulum* S. B., but coarsely-ribbed; 5320, *G.* aff. *striatulum*; 5317 *a*, *G.* aff. *thouarsense*, rather strongly ribbed; 5316, *Pseudogrammoceras* cf. *pachu* S. B., but more finely ribbed (*pedicum* fauna); 5322, *Eseriˑceras* aff. *eseri* (Oppel), but more umbilicate.]		
		Strong parting.		
Lilli (?)	K.	Whitish rubbly limestone. Small *Hildoceras bifrons*, *Rhynchonella* sp.	0	4
		[5211 (2 examples), *Stolmorhynchia bouchardi*/*bothenhamptonensis*.]		
		Obscure parting.		
Bifrons.	L.	Pinkish-yellow conglomeratic limestone. *Hildoceras bifrons.*	0	7
		Obscure parting.		
Falciferum.	M.	Similar limestone, but showing bright red blotches. *Harpoceras falciferum.*	0	6
Pre-*falciferum.*	O.	Very stiff, greyish-yellow, mottled clay. No fossils observed.	0	10
Spinatum.	R.	Oolitic conglomeratic 'marlstone,' with a markedly planed-off top. *Belemnites* spp. common, *Pseudopecten æquivalvis*, *Rhynchonella tetraëdra.*	0	7
		Resting with very irregular base upon		
	T.	Yellowish clayey sands.		

The 'marlstone' of the Down-Cliff sections is almost certainly only the lower layer of that deposit. No evidence of the upper or *serrata* bed was found at Down Cliff, and the planed-off top of the 'marlstone' points to a considerable non-sequence.

The 'marlstone' at Down Cliff rests directly upon the Yellow Sands, without the intervention of the clay-bed seen in Doghus Cliff and Thorncombe Beacon. At the eastern end of Down Cliff

a thin layer of sandy clay is beginning to come in beneath the 'marlstone,' and it thickens rapidly towards Doghus Cliff.

Section III illustrates the thinning-out and change in lithic character of the lenticle of clay O.

SECTION III—THE JUNCTION-BED, MEASURED IN A BLOCK ON THE TALUS AT THE EASTERN END OF DOWN CLIFF.

Hemeræ.		Strata and Fauna.	*Feet*	*inches.*
Bifrons.	L.	Massive mottled limestone. *Hildoceras bifrons.*	1	2
		Obscure parting.		
Falciferum.	M.	Whitish and pink, conglomeratic, mottled limestone; ferruginous near the base.	0	7
		Apparently transitional from		
Pre-*falciferum?*	O.	Greyish-white, nodular, earthy stone, with marly streaks and patches.	0	3–5
		Apparently transitional from		
Spinatum.	R.	Oolitic conglomeratic 'marlstone.' *Belemnites* spp., *Paltopleuroceras* sp. [5168, *Paltopleuroceras* cf. *pseudocostatum* Hyatt, but more spinose.] Seen to	0	8

The 'marlstone' here is almost certainly the lower or pre-*serrata* layer, and the '*Pleurotomaria* Bed' Q is undoubtedly absent: hence the appearance of a transition from R to M must be considered illusory. In formations where 'contemporaneous' erosion has been active (especially if the materials be at all soft) so much intermixture of matrices has taken place along the line of contact of

SECTION IV—THE JUNCTION-BED, MEASURED IN A BLOCK ON THE TALUS BELOW DOGHUS CLIFF.

Hemeræ.		Strata and Fauna.	*Feet*	*inches.*
Bifrons.	L.	Pinkish-yellow mottled limestone. *Hildoceras bifrons*, rolled fragments of *Harpoceras* sp., *Rhynchonella* cf. *moorei*.	0	8
		Obscure parting.		
Falciferum.	M.	Similar, but harder, limestone. Very large *Harpoceras falciferum*, *Dactylioceras* spp., '*Aulacothyris*' sp. [An inverted Terebratulid (5218) a little like *T. aspasia* Meneghini & Zittel, but rounder, not nearly so sulcate, and possessing a smaller beak.]	0	7
		Obscure parting.		
Pleurotomaria ?	Q.	Impersistent earthy ferruginous seam. *Pleurotomariæ*, *Amberleya*, *Cylindrites*, *Trochus*; *Plicatula* cf. *spinosa*.	0	1–2
		Resting upon a rather irregular surface of		
Spinatum.	R.	Rough conglomeratic 'marlstone.' *Paltopleuroceras spinatum*, *Discohelix sinister*, *Pteria* '*inæquivalvis*,' *Pseudopecten æquivalvis*, *Modiola*, *Ostrea*, etc.; *Rhynchonella acuta*, *Rh. furcillata*, *Rh. tetraëdra*, *Terebratula punctata*, *Zeilleria cornuta*, *Z. quadrifida*, *Spiriferina oxygona*. [5137, *Paltopleuroceras* cf. *pseudospinatum* Hyatt, but has many more ribs; 5689 (2 ex). *Homœorhynchia acuta*, medium size; 5361, *Furcirhynchia furcata* S. B.; 1830, *Tetrarhynchia* cf. *tetraëdra*.]	0	9

newer with older deposits, which may be perfectly 'conformable,' that a false appearance of transition results: and such pseudo-sequences may give rise to very erroneous views as to the real importance of formations such as the Junction-Bed or the Inferior Oolite.

I was unable to measure a satisfactory section *in situ* at Doghus Cliff; but some blocks on the talus showed features of considerable interest. Section IV (p. 441), which is taken from one of these blocks, is important, in that it shows what Mr. Buckman considers to be the '*Pleurotomaria* Bed.' The 'marlstone' here does not appear to include any representative of the *serrata* bed. The '*Pleurotomaria* Bed' (?) is impersistent—it is absent from the great majority of the blocks on the talus.

As an illustration of the remarkably variable characters of the Junction-Bed, the following section (V) of another block on the talus of Doghus Cliff is of some interest.

SECTION V—THE JUNCTION-BED, MEASURED IN A BLOCK ON THE TALUS BELOW DOGHUS CLIFF.

Hemeræ.		Strata and Fauna.	*Feet*	*inches.*
Lilli (?).	K.	White rubbly limestone, with ochreous nodules. Worn *Hildoceras* aff. *bifrons*, *Dactylioceras* spp.; *Rhynchonella* sp. [1763, 4994, 5279, 5308, micromorph Dactyloids presenting the aspect of *Ammonites dayi* Reynès; 5278, micromorph Dactyloid of *Cœloceras* aspect; 1777, 4991, 5212 (2 examples), 5309, *Stolmorhynchia bothenhamptonensis* Walker.]	0	3
		Very obscure parting.		
Bifrons.	L.	Pinkish-yellow mottled limestone. *Hildoceras bifrons.*	0	10
		Resting upon the markedly planed-off top of		
Serrata-spinatum.	P+R.	Light-brown oolitic 'marlstone,' becoming rough and conglomeratic towards the base. Many small gastropods (*Amberleya*, *Cerithium*, *Pleurotomaria*, *Trochus*, etc.) near the top. *Rhynchonella acuta*, *Rh.* spp., *Zeilleria cornuta*, *Spiriferina* sp., *Serpulæ*, etc. [5155 (2 ex.), 5687, *Homœorhynchia acuta* (large); 5163 (2 ex.), *Rudirhynchia* sp. = *Rhynchonella fallax* (Deslongchamps) Walker, but presumably new; 5360, *Quadratirhynchia* cf. *crassimedia* S. B.; 5686, *Stolmorhynchia bouchardi*; 5159, *Spiriferina oxygona* Davidson *non* Deslongchamps, cf. *Sp. signensis* Buvignier.]	1	2

Here the *falciferum* layer and the '*Pleurotomaria* Bed' (?) are absent, while the *serrata* bed is present. The lower layer of the 'marlstone' appears to pass up into the *serrata* bed without any break; probably this false appearance of transition is due to a mingling of matrices along the line of junction.

Scattered about on the talus of Doghus Cliff are several large slabs of (presumably) 'Upper Lias' limestone, showing a worn and pitted surface covered with the adherent valves of a small species of *Ostrea* and, more rarely, a large cristate *Serpula*. No

satisfactory evidence sufficient to date the non-sequence thus indicated was observed, and the question must be left open to future research.

The clay which was noted as coming in beneath the 'marlstone' at the eastern end of Down Cliff thickens rapidly under Doghus Cliff, where a thickness of over 10 feet can be seen. The maximum is at Thorncombe Beacon, where the thickness of clay is not less than 16, nor more than 20 feet.

The 'marlstone' attains its maximum thickness in the central portion of the Thorncombe-Beacon cliffs; but, unfortunately, owing to the steepness of these cliffs, it can scarcely be reached *in situ*. However, a very large recent slip has brought down to the shore an abundance of blocks: these yield a rich fauna, and show most of the subdivisions of the Junction-Bed, with the exception of the *striatulum* layer, which, as Mr. Buckman has pointed out,[1] is probably absent from Thorncombe Beacon. Section VI shows two layers N, N_1 not previously noticed.

SECTION VI—THE JUNCTION-BED, MEASURED IN A VERY LARGE BLOCK ON THE TALUS BELOW THE CENTRAL PORTION OF THORNCOMBE BEACON.

Hemeræ.		Strata and Fauna.	Feet	inches.
Falciferum.	M.	Massive limestone, mottled greenish and pink. *Harpoceras falciferum*, *Belemnites* sp.	0	9
		Transitional from		
Pre-*falciferum.*	N.	Earthy ferruginous seam. *Harpoceras* spp., *Phylloceras* sp., *Pteria* '*inæquivalvis*,' *Trapezium* sp., small gastropoda. [5220 *a*, *Harpoceratoides kisslingi* (?) Haug; 5219, 5220, *H.* cf. *kisslingi* Haug, but very finely ribbed; 5169, a micromorph *Phylloceras*, like *Ammonites calypso* D'Orbigny, 'Terr. Jurass.' 1845, pl. cx, but with straighter constrictions and a smaller umbilicus.]	0	2-3
		Obscure parting.		
Pre-*falciferum.*	N_1.	Hard, greyish-white, nodular, earthy limestone with *Harpoceras* spp. at the top of the bed. The lower portion of the bed is a soft yellowish-white rock with scattered oolitic grains, which appears to pass imperceptibly into the earthy limestone at the top. *Rhynchonella acuta* (?), *Rh.* sp. in the lower portion. A layer of large *Belemnites* spp. near the base. From the top of the bed: [5222, *Harpoceratoides?* aff. *fellenbergi* Haug; 5221, *Harpoceratoides?* sp.]	0	3–5
		Very obscure parting.		
Serrata.	P.	Finely oolitic, light-brown 'marlstone.' *Paltopleuroceras spinatum*, large *Harpoceras* sp., large *Belemnites* spp., *Cerithium* sp., *Pleurotomariæ* spp., *Trochus* sp., etc.; *Pseudopecten æquivalvis*; *Rhynchonella acuta*, *Rh. furcillata*, *Rh. serrata*, *Rh.* '*tetraëdra*,' *Rh.* spp., *Terebratula punctata*, *Zeilleria* spp., *Spiriferina* sp. [5167, a brephomorph of *Paltopleuroceras* cf. *spinatum* (D'Orbigny), showing the coronate stage strongly spined, before the advent of a carina; 5231, Harpoceratoid = *Harpoceras radians* Wright, Mon. Lias Amm. (Pal. Soc. 1882) lxxvi, 4–6.	1	0

[1] Q. J. G. S. vol. lxvi (1910) p. 82.

Hemeræ.	Strata and Fauna.	Feet inches.
	1827, 5191 (4 ex.), *Homœorhynchia acuta* (large); 5156, *Furcirhynchia furcata* S. B.; 5192, *Prionorhynchia serrata*; 5195, *P. quinqueplicata*; 5157 (2 ex.), *Quadratirhynchia* cf. *crassimedia* S. Buckman; 5196, *Stolmorhynchia* cf. *bothenhamptonensis*; 5197, *S. bouchardi*; 5192 *a*, *Rudirhynchia (?)* sp. = *Rhynchonella fallax* (Deslongchamps) Walker, but presumably new; 5194, *Rudirhynchia?* cf. *Terebratula triplicata fronto* Quenstedt; 5160, *Lobothyris punctata*; 1845, *Zeilleria cornuta*; 1844, *Z.* aff. *cornuta*; 5343, *Z.* cf. *quadrifida*; 5161, *Z.* sp.]	
	Apparently transitional from	
Spinatum.	R. Rough conglomeratic 'marlstone,' with large irregular concretions of calcareous sandstone at the base. *Rhynchonella* '*tetraëdra*,' *Rh.* spp., *Terebratula punctata*, *Zeilleria* sp., *Spiriferina* sp., etc. [3726, *Tetrarhynchia media/tetraëdra*; 4956, *Quadratirhynchia* aff. *crassimedia*; 5359, *Q. crassimedia/sphæroidalis*; 4523, *Q.* aff. *sphæroidalis*; 5199, *Lobothyris punctata*; 4951, *L. subpunctata*; 1843, 5190, *Aulacothyris florella*; 1838, 5201, *Zeilleria mariæ*; 5202, *Z. subnumismalis*; 5200, an inverted Terebratulid (gen. nov.); 5331, *Spiriferina oxygona* (Davidson); 1841, 5158, *Sp.* sp. like *oxygona* Davidson, but with a costate fold; 1840, *Sp.* sp. (smooth)—cf. *Spirifer rostratus* Davidson, Mon. Brit. Ool. Lias. Brach. III, 1851, ii, 3.]	0 4–6

The presence of *Harpoceratoides* and the absence of *Paltopleuroceras* indicate that at least the upper portion of layer N_1 belongs to the 'Upper Lias.' The date of the lower portion of N_1 is very doubtful; no fossils of zonal importance were observed, and there are only very obscure indications of any break at the base.

The presence in the *serrata* bed of a large Harpoceratoid bearing a superficial resemblance to *Harpoceras falciferum* is of some interest, in that it enables us to understand how early observers came to record '*Ammonites serpentinus*,' etc., from the 'marlstone' portion of the Junction-Bed. No real credence can be given to the alleged occurrence of typical 'Upper Lias' species in the 'marlstone.'

Pleurotomariæ occur in the *serrata* bed, but no indication of any definite '*Pleurotomaria* Bed' was observed.

The brachiopoda are the most abundant fossils of the two 'marlstone' layers. *Rhynchonella serrata* is fairly common in the *serrata* bed, to which it would appear to be confined. Large specimens of *Rhynchonella acuta*, often in a fine state of preservation, are common in the *serrata* bed; *Rh. acuta* is very much rarer in the basal 'marlstone' layer, so much so that an abundance of that form in a block is strongly suggestive of the *serrata* bed. *Rh. acuta* is markedly rare at Down Cliff, where the *serrata* bed is considered to be absent.

Section VII was measured *in situ* near the eastern end of Thorncombe Beacon, only a short distance east of the position from which the block measured in Section VI must have fallen. It

shows the most attenuated facies of the Junction-Bed yet observed on the coast.

SECTION VII—THE JUNCTION-BED AND CONTIGUOUS DEPOSITS, MEASURED *in situ* CLOSE TO THE EASTERN END OF THORNCOMBE BEACON.

Hemeræ.		Strata and Fauna.	Feet	inches.
Dumortieria.	A + B.	Blue sandy 'Upper Lias' clay. Coarsely-ribbed *Dumortieria* sp. in friable condition.		
		Thin irony scale (impersistent).	0	$0\frac{1}{4}$
Bifrons.	L.	Earthy conglomeratic limestone, with a markedly-smooth top. *Hildoceras bifrons.*	0	5–6
		Strong parting.		
Serrata.	P.	Light-brown, finely oolitic 'marlstone,' yielding *Rhynchonella acuta.* Top planed off very smooth.	0	6–7
		Resting upon		
	S.	Blue-sandy clay.		

Sections I to VII will have served to illustrate some of the extraordinary complexities of the Junction-Bed; a larger number of sections would show still further variations.

A few yards east of Section VII the outcrop of the Junction-Bed leaves the cliff-face, and turns inland; when the Junction-Bed reappears at Watton Cliff, east of Eypesmouth, the whole facies is remarkably changed.

(4) The Watton-Cliff Section.

From the last appearance of the Junction-Bed at the eastern end of Thorncombe Beacon to its reappearance at the western end of Watton Cliff, east of Eypesmouth, there is a gap of some three-quarters of a mile.

At Watton Cliff the Junction-Bed is exposed in a particularly inaccessible position. It forms a kind of projecting cornice, high up in the precipitous face of the cliff, on the upcast side of the great fault that throws 'Fuller's Earth' and 'Forest Marble' against the 'Middle' and 'Upper Lias.' According to the Geological Survey,[1] the downthrow is 'at least 425 feet.'

The only published reference to the existence of the Junction-Bed at Watton Cliff that I have been able to find is the following short and inconclusive note by the Geological Survey *(loc. cit.)*:

'East of Eype the cliff again exhibits a portion of the Middle Lias. At the base there are blue clays with *Ammonites margaritatus*, and these are succeeded by the Starfish Bed, the Laminated Beds, and Yellow Sands. These are capped by grey shaly beds, that include a hard band that may be the Junction-Bed of Middle and Upper Lias, with perhaps some portions of the overlying Upper Lias. The higher strata were, however, difficult of access.'

It seems somewhat remarkable that this unique section should have escaped general notice for so many years. It is quite easy to observe from the talus that the Junction-Bed is much thicker here than in the Western Cliffs.

[1] 'The Jurassic Rocks of Britain: the Lias of England & Wales' Mem. Geol. Surv. vol. iii (1893) p. 200.

SECTION VIII—THE JUNCTION-BED, MEASURED ON A BLOCK ON THE TALUS AT THE WESTERN END OF WATTON CLIFF, EAST OF EYPESMOUTH.

Hemeræ.	Strata and Fauna.	*Feet*	*inches.*
Dumortieria.	A. Traces of blue sandy 'Upper Lias' clay.		
	Transitional from		
	B. Hard, sandy, ferruginous clay with ochreous veins. Coarsely-ribbed *Dumortieriæ* in friable condition; obscure gastropod-remains, fragments of *Isocrinus* sp.	0	3–5
	Transitional from		
	C. Whitish earthy limestone in two irregular layers. A seam of small slender *Belemnites* sp.	0	2–5
	Non-sequence.		
[*Hammatoceras ?*]	D. Intensely hard, finely laminated, lithographic limestone; the laminæ are of various shades of pale brown and bluish grey. The lower portion splits readily into thin platy slabs, covered with fine dendrites; the upper portion is more massive, and breaks with a sub-conchoidal fracture. Many finely-preserved ammonites; no other fossils observed.	0	7–8
	[5323, *Alocolytoceras* cf. *germaini* (D'Orbigny), a smooth cast, ornament almost obliterated; 5684, *Frechiella* aff. *subcarinata* (Young & Bird), a brephomorph, beautifully preserved, with white matrix in the body-chamber: this shows the transition from *Cymbites* to the *Paroniceras* stage, but has not got to the *Frechiella* stage of bisulcate periphery; 5324, 5325*a* & *b*, 5680, 5682, costate forms, more than one species, like *Ammonites rugatulus* Simpson, also like *A. multifoliatus* Simpson, but more costate; 5325, 5679, 5679*b*, costulate to capillate forms, like *A. similis* Simpson, but thinner; 5325*c*, a micromorph of, presumably, *Grammoceras-striatulum* type.]		
	Impersistent earthy parting: non-sequence.		
	D_1. Intensely hard, greyish-yellow, non-laminated, sandy limestone. No recognizable fossils, except fragments of a small *Rhynchonella* sp.	0	5–6
	Apparently transitional from		
	D_2. Massive cream-coloured limestone. *Belemnites* sp.	0	4–5
	Apparently transitional from		
	D_3. Cream-coloured shelly limestone, crowded with *Grammoceras* sp. [5326, *G.* aff. *thouarsense*], especially at the base. Many minute gastropoda: *Amberleya*, *Ataphrus*, *Cerithium*, *Cryptænia*, *Trochus*, etc.; *Rhynchonella* sp., *Isocrinus* sp., echinoid radiole.	0	3–4
	Apparently transitional from		
	D_4. Pale cream-coloured laminated limestone.	0	3
	Distinct parting.		
	D_5. Compact, cream-coloured, laminated limestone, somewhat false-bedded on a minute scale. Fragment of *Nautilus* sp., *Ataphrus* sp.	0	2–10
	Resting unconformably upon		
[*Thorncombiensis.*]	U. Hard yellowish-brown ferruginous rock of 'marlstone' type, almost identical in lithic characters with the *T.-thorncombiensis* Bed of the Western Cliffs. *Rhynchonella* sp. [*Tetrarhynchia thorncombiensis*] common; *Belemnites* sp.; fragment of large *Harpoceras* on the top of the bed, but probably not belonging to it.	0	0–10
	Very irregular base.		
Falciferum ?	M ? Massive, pinkish and yellow mottled limestone.	0	8–9
	Very obscure parting.		
	M_1 ? Similar, but harder limestone. Seen to	0	9–10

There is only one place where it is at all possible to reach the Junction-Bed *in situ* with any degree of safety—a kind of shallow gully or slide, descending from the top of the cliff along the line of fault to the top of the extensive overgrown talus between the inner cliff and the foreshore. I measured a section in the Junction-Bed immediately above a group of three very big fallen blocks on the talus. The total thickness was 4 feet 7 inches; but the only part that could be reached was a joint-face, covered with stalactitic matter which prevented me from recording any detailed measurements. Another section, measured *in situ* a few yards farther east, will be described later on. The accompanying section (VIII) was taken from one of a group of three immense fallen blocks. Other blocks show a very similar development of the Junction-Bed, but with minor variations.

The whitish earthy limestone (C) forms a kind of capping to the lithographic stone (D); but a close examination shows that there is no transition. The base of C fills shallow hollows in D, and cuts across the planes of lamination. The thickness of C is very variable. No fossils of zonal importance were seen.

Little more can be said concerning layer D. Mr. Buckman writes (*in litt.*, February 1921): 'the date of D is very uncertain.' Layers D to D_5 are closely associated, and form a group with very similar lithic characters, but there are small non-sequences. The abundance of minute gastropoda in D_3 is noteworthy.

Below layer D_5 the sequence is very doubtful, and difficult to determine. The rock resembling 'marlstone' (U) is a wedge-shaped mass, about 3 feet long, presumably a portion of a large slab or lenticular cake of stone derived from some lower horizon. Mr. Buckman has determined the *Rhynchonella* to be *Tetrarhynchia thorncombiensis*, which is abundant in a bed some little distance down in the Yellow Sands of the Western Cliffs. Presumably, therefore, this redeposited mass was derived from the *T.-thorncombiensis* Bed. Other blocks show similar lumps of stone, and derived specimens of *T. thorncombiensis* and *Belemnites* sp. are common.

The age of layers M (?) and M_1 (?) is doubtful. In lithic characters they remind one of the more massive portions of the *falciferum* layer of the Western Cliffs, and are very similar to layer M_1 (?) of Section IX (which yielded some big specimens of *Harpoceras falciferum*). In some blocks pieces of the *T.-thorncombiensis* Bed and redeposited *Rhynchonellæ* are enclosed in the limestone layers M (?) and M_1 (?).

At Watton Cliff the clay below the Junction-Bed is absent, and the presence of derived masses of the *T.-thorncombiensis* Bed indicates that erosion has removed some thickness of the upper portion of the Yellow Sands.

Section IX (p. 448) was measured *in situ* immediately west of the point where the Lias is finally cut off by the faulted Bathonian rocks, and only some 30 feet east of the position from which the block measured in Section VIII must have fallen.

Section IX—The Junction-Bed and Contiguous Deposits, measured *in situ* at the Western End of Watton Cliff.

Hemeræ.		Strata and Fauna.	Feet	inches.
Dumortieria.	A + B.	Blue sandy 'Upper Lias' clay.		
		Marked non-sequence.		
Falciferum ?	M (?).	Very hard mottled limestone, with large *Harpoceras falciferum* common at the top. [5230, *Harpoceras* cf. *mulgravium.*] Top much iron-stained and planed off smooth.	0	8–9
		Transitional from		
	M_1 (?).	Harder, conglomeratic, mottled limestone. Small *Harpoceras ?* sp. near the top. [Micromorph, not *Harpoceras.*]	0	10–11
		Irregular parting.		
[*Thorncombiensis.*]	U (?).	Soft, earthy, yellowish 'marlstone.' *Belemnites* sp., *Syncyclonema* sp., *Rhynchonella* sp. [5232, *Tetrarhynchia thorncombiensis*].	0	6
		Apparently transitional from		
	U_1 (?).	Rough lumpy 'marlstone,' soft and highly ferruginous.	0	6
		Apparently transitional from		
	U_2 (?).	Soft earthy 'marlstone' crowded with crinoid fragments.	0	2–3
		Apparently transitional from		
		Lumpy ironshot marlstone, somewhat oolitic.		
	U_3 (?).	Obscure fragment of *Harpoceras* in friable condition. Seen to	0	7
		(About 1 foot obscured by slipped material.)		
	T.	Soft yellow sands.		

The most interesting feature of this section is the absence of the lithographic and other limestones of layers D to D_5. That all these beds should have disappeared in so short a distance is a good example of the remarkably sudden variations to be met with in the Junction-Bed.

Layers M (?) and M_1 (?) are almost certainly the continuation of layers M and M_1 (?) in Section VIII. Presumably layer M (?), at least, is of *falciferum* date—unless the specimens of *Harpoceras falciferum* are redeposited.

Layers U (?) to U_3 (?) are only separable with uncertainty, as the deposit is very irregular, lumpy, and confusedly mingled. The fossils characteristic of the 'marlstone' of the Western Cliffs appear to be absent, and much of the rock is more like the *Tetrarhynchia-thorncombiensis* Bed and other hard bands in the Yellow Sands than the true 'marlstone.' Mr. Buckman considers that the whole of layers U (?) to U_3 (?) is pre-*spinatum* material redeposited.

[During further work in 1921 I discovered a block of the Junction-Bed (about 8 feet long) lying partly embedded in talus some few feet west of the group of three blocks measured in Section VIII. At the eastern end, the 'Upper Lias' clay A + B rests upon the earthy limestone C (4 to 5 inches) and the lithographic stone D (7 to 8 inches); at the western end it rests upon the grey limestone D_1, C and D having been removed by denudation prior to the deposition of the 'Upper Lias' clay.]

Appendix II—The Upper Lias Succession. By Leonard Frank Spath, D.Sc., F.G.S., John Pringle, F.G.S., Andrew Templeman, and S. S. Buckman, F.G.S.

(A) Introduction. (S. S. B.)

Some time after my paper had been sent in to the Society, some important excavations were made in the Upper Lias of Somerset, which throw much light on the points discussed in pp. 390–395. Dr. Spath sent me a summary of the results that he had obtained from a study of a collection made by Prof. D. M. S. Watson: this communication is placed first, because it enters into considerable detail as regards the genera and species of ammonites. Later, Mr. Pringle and Mr. Templeman forwarded a summary of the results of their collecting—particularly important because the beds were collected from almost inch by inch, with extremely happy results. They did not attempt much particularization of ammonites, because their finds were placed in my hands for detailed work. But, although such detailed work cannot be undertaken for some time, it has been possible to make a general survey of the faunal succession. From this information and the study of some Northamptonshire specimens submitted by Mr. Pringle at the same time, it has been possible to construct succession and correlation tables, which, although necessarily imperfect in certain respects, will (it is hoped) become useful bases for further work.

(B) Upper Lias Succession near Ilminster, Somerset. (L. F. S.)

This succession is based on material collected and submitted by Prof. D. M. S. Watson, to whom grateful acknowledgments are tendered. Beds 13 to 15 were collected from at Barrington, beds 4 to 12 at Stocklinch. The highest bed ('Top-Rock' 13) at the latter locality did not yield any ammonites; but Prof. Watson has reasons for considering beds 13-15 to follow on bed 12, as in the succession tabulated below.

Strata.	Horizons.
(a) *Barrington.*	
15. 'Basement Bed of Yeovil Sands' .... (*Phlyseogrammoceras dispansum*, *Dumortieria ?* sp., *Alocolytoceras ?* sp. juv.)	*Dumortieria ?* to *dispansum.*
14. 'Black Clay,' 6 inches (fauna derived) .... (*Hammatoceras* cf. *insigne*; *Grammoceras* spp.; *Pseudogrammoceras ?* cf. *grunowi* (Dumortier,[1] *non* Hauer); *Haugia* sp.; v-script *Hildoceras.*)	*struckmanni ?* to *striatulum.*
13. 'Top-Rock' (*Phymatoceras ?* cf. *werthi*)	*variabilis ?*

[1] 'Études Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône : Lias Supérieur' vol. iv (1874) pl. xiv, figs. 6 & 7.

Strata.	Horizons.
(b) *Stocklinch.*	
12. Top 3 feet. (Zones not separated in collecting.) ... (*Hildoceras bifrons, H. walcottii* etc.; a stout Dactyloid *(Porpoceras?)* and vermiform *Dactylioceras.)*	*bifrons*, etc.
11. Above Fish-Bed 7 feet 6 inches .... (*Ammonites levisoni*, auctt. *non* Simpson; a stout Dactyloid, more finely còstate than '*Cœloceras*'[1] *crassoides*, below.)	*Hildoceratoides.*
10. Above Fish-Bed 7 feet .... (Many young *Harpoceras*; *Hildoceratoides* sp. (of *Mercaticeras* aspect); *Dactylioceras* cf. *vermis*; '*Cœloceras*' cf. *fonticulum.*)	*falciferum* B.
9. 'Brown Bed' (above Fish-Bed 6 feet 6 inches) ... (Main development of *Harpoceras falciferum* sensu stricto; '*Cœloceras*' cf. *crassoides.*)	*falciferum* A.
8. Above Fish-Bed $5\frac{1}{2}$ to 6 feet .... (*Hildaites levisoni* Simpson and *Hildaites* cf. *chrysanthemum* Yokoyama sp.[2]).	*Hildaites.*
7. Above Fish-Bed $4\frac{1}{2}$ to 5 feet .... (*Dactylioceras anguinum* (Reinecke) and other, more vermiform, *Dactylioceras.*)	*anguinum.*
Beds 7–11 with *falciferum*-like *Harpoceras* throughout.	
6. Above Fish-Bed 18 inches to $4\frac{1}{2}$ feet (no yield) ...	?
5. Above Fish-Bed 18 inches .... (*Harpoceratoides*, large form, more finely costate than those below.)	?
4. Above Fish-Bed 1 foot .... (*Harpoceratoides alternatus, H. kisslingi*, etc.; *Dactylioceras helianthoides* Yokoyama, '*Cœloceras*' sp. juv.; *Phylloceras* sp.; *Elegantuliceras* sp.)	*Harpoceratoides.*
3. Fish-Bed (Clay 18 inches), no yield	?
2. *Leptæna* Bed (1 foot), no yield	?
1. Marlstone.	

(C) Two New Sections in the Middle and Upper Lias at Barrington, near Ilminster, Somerset. (J. P. & A. T. Notes in brackets by S. S. B.)

During the year 1920 a quarry was opened in a field on the west side of the cross-roads between Barrington and Stocklinch, and 650 yards south-west of Barrington Church. In the excavation, which was carried down to the base of the Marlstones, about 14 feet of Upper Lias clay and limestones are exposed. An abstract of these beds, numbered in ascending order from 1 to 26, is set forth in the appended section (p. 451). Fuller details await a critical examination of the ammonites.

In the same year a smaller quarry was opened on the west side of Shelway Lane, Barrington; it shows a similar sequence of Middle and Upper deposits on the eastern side of the pit. Beds 1–26 of the Upper Lias can again be seen; but in the roadside above the quarry and in the bank above the adit on the east side of the road additional strata are exposed, carrying the section up

[1] *Cœloceras* sensu stricto, restricted to the *pettos* group, in L. F. Spath, 'Notes on Ammonites' Geol. Mag. 1919, p. 28.

[2] 'Jurassic Ammonites from Echizen & Nagato' Journ. Coll. Sci. Tokyo, vol. xix, No. 20 (1904) pl. ii, fig. 1.

to the brown sands, which are believed to be of *dispansum* date. These higher beds are numbered in continuation with the larger quarry. It should be noted here that the Shelway-Lane quarry also shows a remarkable local wash-out, probably of recent geological date. On the west side of the pit all of the beds above the Marlstone have been broken up to the depth of 14 feet, and re-arranged.

Section I—Lias, Barrington (Epitome).

(A) Shelway Lane, Barrington.

No.	Strata.	Thickness. Feet	inches.	Horizon.
Upper Lias.				
32.	Sand	6	0	*dispansum.*
31–29.	Clays and limestones, unfossiliferous	2	6	
28, 27.	Do. fossiliferous	3	8	

(B) Barrington Quarry.

No.	Strata.	Feet	inches.	Horizon.
26–24.	Clays and limestones, *Hildoceras*	3	8	*bifrons* [12, 11, Spath].
23.	Reddish-brown clay, pinkish-grey limestone	0	7	[10, Spath.]
22.	Whitish clayey limestone	1	0	
21.	Olive-grey clay, with *Crania* = *Crania*-Clays of Moore	0	5	
20.	Pink-tinged, grey, clayey limestone. *Hildoceras* [Not *Hildoceras*; a new form.]	0	5	[pre-*bifrons.*]
19.	Clay and limestones. Large Harpoceratids, *Cœloceras*	0	8	[9, Spath.] *falciferum*
18.	Do.	0	3	[8, Spath.]
17.	Do., *Dactylioceras*	0	3	[7, Spath.]
16–12.	Do.	1	1	[6, Spath.]
11.	Do., *Harpoceras*	0	5	
10–8.	Do.	0	10	[5, Spath.] [Moore's zone of *Rh. bouchardi.*] (8–7)
7.	Do., *Rhynchonella bouchardi*, *Harpoceratoides*	0	7	
6.	Do., *Harpoceratoides*	0	3	[4, Spath.] (6–5)
5.	Laminated clay, *Harpoceratoides*	0	5	
4.	Fish-Bed	0	3	*exaratum.*
3.	*Leptæna* Clays of Moore	2	0	
2.	Top bed of Moore's Middle Lias: bed F of his Ilminster section. *Dactylioceras* spp.	0	4	*tenuicostatum.*
1.	Sandy marl; large belemnites, finely ribbed Dactyliocerates [Impression of *Paltopleuroceras* cf. *hawskerense.*]	0	7	
Middle Lias.				
2.	Marlstone Rock-Bed, 7 feet thick. A layer of sandy marl 6 to 9 inches from the top [contains degenerate Paltopleurocerates, cf. *Paltopleuroceras regulare* Simpson sp.]	7	0	*acutum.* [*regulare.*] *spinatum.*
1.	Sands.			

(D) Upper and part of the Middle Lias Succession, and Correlation. (S. S. B.)

In his examination of Prof. Watson's collection Dr. Spath was able to make certain notable additions to the recognizable horizons of the Upper Lias: he was able to place as chronological indices two new genera which I had recently named and illustrated in 'Type-Ammonites'—*Hildaites* (pl. ccxvii) and *Hildoceratoides* (pl. ccxviii). Further, he distinguished a horizon by the name *anguinum*, and placed *Harpoceratoides* as marking a distinct date: species of this genus had been obtained by Mr. J. F. Jackson from the Junction-Bed of the Dorset Coast (see p. 443); but on that evidence alone it had not been considered advisable to distinguish *Harpocerotoides* as a separate time-term. Now all this evidence falls nicely into line.

Adopting Dr. Spath's terms, and using information otherwise obtained, it is possible to present the following sketch of the chronological sequence in the Upper Lias (and top of the Middle Lias) —Table VI, p. 453. At the same time, a series of stratigraphical terms are appended which may be useful to the memory, as well as indicating where certain beds are well exposed. It is not intended to say that the beds are only exposed at the places which give their names: it is known, for instance, that Whitby possesses far more than the strata of the three hemeræ which stand opposite 'Whitby Beds.' But, on the other hand, deposits of certain hemeræ seem only to have been preserved at the localities which give their names: thus the strata of *pseudovatum* date are only known in Yorkshire.

A similar phenomenon attends *exaratum*: this species has not been recognized outside of Yorkshire. Several of the associates of *exaratum* in the Jet-Rock of Yorkshire have now been found in other localities—for instance, in the *Leptæna* Bed of Somerset, where the inch-to-inch collecting gives them a certain sequence, which, however, must be taken with some reserve: first, because the present examination is necessarily rather cursory, and, secondly, because the specimens are somewhat crushed and ill-preserved. But the important fact is that, while the *Leptæna* Bed yields these *exaratum* associates, another of the Jet-Rock genera (*Harpoceratoides*) is found in a bed of different lithic character at a distinctly higher level—separated from the *Leptæna* Bed by the Fish-Bed. Therefore, it may be argued that the Yorkshire Jet-Rock is not a deposit of one date, but is polyhemeral.

The exact chronological position of *exaratum* is, then, uncertain. There is little doubt that it has some affinity with the forms now spoken of as 'Grantham ammonites,' and it is therefore concluded that its date is either just before or just after those forms. If placed before the Grantham ammonites, a non-sequence in the *Leptæna* Bed is produced, and a considerable non-sequence in the

TABLE VI—SKETCH OF THE CHRONOLOGICAL SEQUENCE IN THE UPPER LIAS.

Ages.	Bed Nos.	Hemeræ.	Strata.
Yeovilian.		9. *moorei.*	
		8. *Catulloceras.*	Yeovil Sands.
		7. *Dumortieria.*	
		6. *Hammatoceras.*	Bruton Sands.
		5. *dispansum.*	Frocester Beds.
		4. *struckmanni.*	Midford Sands.
	U.L. 28.	3. *pedicum.*	Stinchcombe Beds.
		2. *eseri.*	
		1. *striatulum.*	Sodbury Sands.
Whitbian.	U.L. 27 *c.*	26. *variabilis.*	
		25. *lilli.*	Cotteswold Sands.
	U.L. 27 *b.*	24. *semipolitum.*[1]	
	U.L. 27 *a.*	23. *subplanatum.*	
		22. *braunianum.*	Northampton Beds.
		21. *fibulatum.*	
	U.L. 26.	20. *bifrons.*	
	U.L. 25 ?	19. *subcarinata.*	Whitby Beds.
		18. *pseudovatum.*	
	U.L. 24.	17. Gen. and sp. nov. (small Harpocerate.)	
	U.L. 23.	16. *Hildoceratoides.*	
	U.L. 19.	15. *falciferum.*	Barrington Beds.
	U.L. 18.	14. *Hildaites.*	
	U.L. 15.	13. Cf. *Pseudolioceras.*	
	U.L. 11.	12. *anguinum.*	
	U.L. 7.	11. *Harpoceratoides.*	
		10. *murleyi.*	Dumbleton Insect-Bed.
		9. *exaratum.*	Boulby Bed.
		8. biform Harpocerates.	Grantham Bed.
	U.L. 3.	7. *Eleganticeras.*	Yorkshire Jet-Rock.
		6. *Elegantuliceras.*	
		5. *tenuicostatum.*	Yorkshire Grey Shales.
		4. *Tiltoniceras.*	Tilton Beds.
	U.L. 2.	3. *athleticum.*	
	U.L. 1.	2. fine-ribbed Dactyloids.	Stocklinch Bed.
		1. Harpoceratoid.	Chideock Bed.
Domerian.	M.L. 1.	2. *hawskerense.*	Hawsker Beds.
		1. *spinatum.*	South Petherton Beds.

Jet-Rock; if placed afterwards, the former is avoided at the expense of a double non-sequence in the Jet-Rock. Further evidence is required.

As the evidence for the chronology of the earlier hemeræ of the Upper Lias is somewhat imperfect, the correlation-table (VII, facing p. 454) has been drawn up, chiefly in order to compare Somerset with Yorkshire. The lacunæ in the intervening areas are not all to be read as non-sequences: they arise from lack of evidence, collection-failure, exposure-failure, nomenclature-failure, and so on. It is doubtful whether anything like the full sequence of the early hemeræ of the Whitbian has yet been obtained.

[1] *Hildoceras semipolitum*, S. Buckman, is the particular species of the lower part of the Cotteswold Sands; evidence for *Lillia lilli* and its associates in that deposit is lacking, but there is plenty of room for them. Very little collecting has been done in this deposit, which sometimes is 250 feet thick.

A last word may be added concerning the Japanese species *Dactylioceras helianthoides* Yokoyama. Dr. Spath quotes this from above the Fish-Bed: I quote something like it from well below. The Dactyliocerates are a very difficult group, occurring in the Upper Lias in seemingly endless variety. When it was thought that the Upper Lias was laid down at about three different dates, such endless variety of apparently contemporaneous forms was difficult to understand. When it is seen that the dating of the Upper Lias (the Dactyliocerate part—the Whitbian) has to be multiplied some eight times and, therefore, the number of contemporaneous species has to be divided eight times, the diversity of the Dactyliocerates becomes more comprehensible: they represent waves of more or less closely-allied lineages, which develop and tail-off (degenerate) in somewhat similar fashion, producing homœomorphous forms.

It was necessary to be satisfied, in regard to the finely-ribbed Dactyliocerates below the Fish-Bed, that they were not *D. tenuicostatum* of the Yorkshire Grey Shales: they are not, but they have a likeness to *D. helianthoides*. When really systematic research-work on the Dactylioceratidæ can be undertaken—at present such work is only in its infancy,—it will doubtless be found that the points of difference between similar-looking forms are more important than is now suspected. When these differences can be recorded and brought to bear on species of known date in an extended time-scale, one may expect the Dactylioceratidæ to become very useful chronological indicators.

IX. Summary.

(1) The body of the paper deals with certain Jurassic strata near Eypesmouth on the coast of Dorset; but, as it forms part of a series of preliminary studies in connexion with Jurassic chronology, certain details connected with other localities are noticed.

(2) A general section of the main mass of Watton Cliff east of Eypesmouth is given.

(3) A detailed section is recorded of a remarkable white lithographic bed in Watton Cliff, one in the same position as the Upper and Mid-Lias Junction-Bed of the Thorncombe-Beacon area, but differing much in faunal and stratal details.

(4) This bed shows faunal inversion, presumably due to redeposition of material from older deposits.

(5) The dating of this Watton Bed is discussed, after preliminary investigations into the sequence of horizons in the Upper Lias of various areas, in the Junction-Bed and pre-Junction-Bed strata of Thorncombe Beacon.

(6) A theory of stratal repetition and coalescence is discussed in regard to the Watton Bed. Its main date is taken to be Yeovilian, *Hammatoceras* hemera.

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TABLE VII.—CORRELATION OF THE UPPER LIAS (WHITBIAN—EARLIER HEMERÆ) AND THE LAST PART OF THE DOMERIAN.

	Dorset Coast.	Somerset (Barrington).	Gloucestershire (Stinchcombe).	Gloucestershire (Dumbleton).	Northamptonshire (Byfield, etc.).	Lincolnshire (Grantham, etc.).	Yorkshire (Whitby neighbourhood).	
11.	*Harpoceratoides.*	*Harpoceratoides.*			Fish-Bed: Cf. *Harpoceratoides.*		Jet-Rock: *Harpoceratoides.*	11.
10.		Fish-Bed.		Insect-Bed; *murleyi.*				10.
9.							*exaratum.*	9.
8.		L. ptæna-Bed: Grantham Ammonites (biform Harpocerates).		*Leptæna*-Bed equivalent.	Grantham Amm.	Grantham Amm.		8.
7.		*Eleganticeras.*					*Eleganticeras.*	7.
6.	*Elegantuliceras*-like forms.	*Elegantuliceras.*					*Elegantuliceras.*	6.
5.					Transition-Bed: Sandy clay.		Grey Shales: *tenuicostatum.*	5.
4.			*Tiltoniceras* (Thin seam resting on Middle Lias Rock-Bed).		*Tiltoniceras.*	Transition-Beds: *Tiltoniceras.*	*Tiltoniceras.*	4.
3.	*athleticum*-like forms.	Middle Lias, Moore: *athleticum*-like forms.			Dactyloids, cf. *athleticum.*	Dactyloids.	Middle Lias, *auctt.*: *athleticum.*	3.
2.		Fine-ribbed Dactyloids, not *D. tenuicostatum*, cf. *D. helianthoides.*						2.
1.	Harpoceratoid Ammonite.							1.
2.	*Paltopleuroceras* degenerates.	*Paltopleuroceras*-*hawskerense* and *regulare* forms.	Rock-Bed: *P.* cf. *hawskerense.*				*P. hawskerense.* *P. regulare.*	2.
1.	*Paltopleuroceras*-*spinatum* forms.	*P.-spinatum* forms.		*P.-spinatum* forms.				1.

(7) The white lithographic bed of Burton Bradstock is cited as evidence of stratal repetition, and a theory as to the deposition and almost complete destruction of this Burton bed is put forward.

(8) The Watton and Burton lithographic beds are cited as evidence of Alpenkalk conditions prevailing in Western Europe during two well-separated Jurassic dates, both of them far earlier than the times of Alpenkalk deposits in Central and Eastern Europe.

(9) Certain remarks are made upon sections at Milborne Wick and Haselbury (Somerset) with regard to the dating of their deposits, and a table of the succession and distribution of Hammatoceratids is given.

(10) A palæontological note describes a new species of Rhynchonellid—*Tetrarhynchia thorncombiensis* (*Rhynchonella northamptonensis* auctt., passim)—a species marking a particular deposit at Thorncombe Beacon.

(11) An Appendix by Mr. J. F. Jackson gives the result of his studies of various sections of the Junction-Bed (including the Watton Bed) on the Dorset coast,

(12) A second Appendix gives studies by Dr. L. F. Spath and by Mr. J. Pringle & Mr. A. Templeman of the stratal and faunal (ammonite) succession revealed by certain new exposures in the Upper and Middle Lias near Barrington (Somerset)—the collecting of specimens having been done almost inch by inch.

(13) The evidence thus obtained, added to that gleaned elsewhere, some of it set out in the body of the paper, enables the Author (S. S. Buckman) to put forward a tabular sketch of Upper Lias chronology more detailed than has yet been attempted—dividing the ages (Yeovilian and Whitbian) of the Upper Lias into thirty-five hemeræ—more divisions than were originally made by Oppel for the whole of the Jurassic.

Discussion.

Mr. J. Pringle said that, as joint author of one of the Appendices, he would refer to the salient features of the work done by Mr. A. Templeman and himself on the Upper Lias exposed in certain quarries at Barrington. These beds had been described by Charles Moore, and the reopening of the sections after a long period of disuse had provided an opportunity of examining the Upper Lias, with a view to the correlation of the deposits with those of the Banbury district. The section was carefully collected over bed by bed, and more than a thousand specimens of ammonites were secured. The value of the results obtained had been much enhanced by Mr. Buckman's co-operation.

Dr. A. Morley Davies said that the deposits in a shallow sea transgressing over an area where folding and faulting movements

were still in progress, might very well show such anomalies as the Author described. He found it difficult to believe, however, that the beautifully preserved ammonite exhibited, with similar matrix within its body-chamber and around it, could be a derived fossil. He enquired whether the *bifrons* ammonites which appeared in inverted sequence in this new junction-bed showed the same pink colour as that which characterized their matrix in the well-known Junction-Bed.

Dr. W. D. Lang asked whether a simpler explanation than that suggested by the Author might not be applicable to the inverted sequence of ammonites in the Junction-Bed at Eype, namely, a long period of very slow deposition coinciding with an oscillation of surface at about sea-level, allowing wave-action to mingle the fossils of successive faunas, and even to remove a certain amount of sediment; the whole deposit being subsequently consolidated by a segregation of calcium carbonate. If the last-mentioned process took place, it would be unnecessary to consider, as the Author apparently did, that the Junction-Bed was a deep-water deposit. That such segregation would not necessarily do away with the bedding-planes could be seen in the concretions of the *birchi* nodular deposit, occurring in the Lower Lias of the same district. Bedding was very apparent in these nodules.

Prof. P. G. H. Boswell said that, among the many interesting questions raised by the Author, that of the evidence of shallowing conditions and instability in the area during the period covered by the hemeræ from *lilli* to *opaliniformis* deserved emphasis. The sandy facies which stretched from the Cotteswolds to the Dorset coast, and included the uppermost zones of the Lias and lowermost zones of the Inferior Oolite, was characterized throughout by the constancy of its peculiar lithological and petrographical characters. As the Author had proved many years ago, this sandy and silty phase transgressed as a wave of shallowing conditions to successively higher horizons as the observer travelled southwards, thus providing an admirable example of the transgression of time-planes by lithological planes.

Mr. G. W. Lamplugh thought it improbable, on the evidence adduced, that the comparatively large and well-preserved ammonites found in the narrow band of fine-grained laminated material at Watton Cliff could have been derived at recurrent intervals from older strata and redeposited in inverted order. Judging from the specimens exhibited, he suggested that the bed might be a 'condensed' deposit, very slowly accumulated and covering a long period. In such beds the rare accident of preservation at intervals was likely to bring about the juxtaposition of forms not truly contemporaneous. The further accident of collecting-chances in beds of this kind rendered the basis for the hypothesis still narrower.

The Author, in reply, said that the Watton-Cliff bed presented a mass of puzzles, and the point raised by Dr. Davies—the difficulty of derivation in the case of well-preserved fossils—was a problem already noted, not only for this instance. The solution in some

cases was that specimens had been redeposited inside lumps of original matrix. Big lumps of derived matrix were in the Watton bed, but there arose the difficulty of reconciling such lumps with a fine-grained laminated deposit—the former indicated violent action, the latter very tranquil conditions and, possibly, deep water. The tranquil conditions seemed to be inconsistent with the wave-action suggested by Dr. Lang.

The Author agreed with Mr. Lamplugh that the Watton Bed was a highly condensed deposit: it had taken the whole of the time of the Upper Lias—some thirty hemeræ—to deposit 5 feet; but the question was whether the deposit as seen now represented anything like the original mass laid down. The Author supposed not. How much had been removed by penecontemporaneous erosion without leaving a trace behind?

With reference to Mr. Pringle's remarks, the Author wished to acknowledge how greatly he was indebted to his collaborators for their Appendices, representing a mass of new observations supplementing his paper. The most interesting point, perhaps, was that the system of many chronological divisions, which the Author might claim to have originated, had been extended by his collaborators: that testimony to his moderation was welcome; because his original number of subdivisions had often been condemned as excessive. He had always been compelled to go on asking for more, and now other investigators went farther still. This constant lengthening of the Earth's chronology was particularly interesting.

In noting that palæontological planes did not coincide with lithological planes, Prof. Boswell had, as he said, drawn attention to the Author's work of many years ago. It was a vindication of the subdivisional method that it had given these results so clearly, and had shown the uselessness of lithology as a guide to date.

GENERAL INDEX

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